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VEHICLE EMISSIONS RESEARCH LABORATORY

EMISSIONS FROM A GASOLINE- AND DIESEL-POWERED MERCEDES 220 PASSENGER CAR

by
Karl J. Springer

Prepared for
Division of Emission Control Technology
Air Pollution Control Office
Environmental Protection Agency
Contract No. CPA 70-44

June 1971

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This project investigated emissions from a typical car with a diesel engine, the Mercedes Benz 220D, and a comparative car with a gasoline engine, the Mercedes Benz 220. Both hydrocarbon and carbon monoxide emissions were over 90% lower in the diesel vehicle. Nitrogen oxides emissions were 50% lower in the diesel vehicle. Other emissions including aldehydes were also measured. The 1972 Federal Test Procedure (CVS) was used for these tests.

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Details of illustrations in this document may be better studied on microfiche

June 1971

Approved:

John M. Clark, Jr., Director
Department of Automotive Research

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I. INTRODUCTION

In the search for a low pollution automotive powerplant, the diesel has too readily been associated with its sister engine, the spark-ignition engine which operates on gasoline. Though some diesels emit noticeable smoke and/or odor under some operating conditions, both are classed as nuisance emissions and not health hazards in themselves. Most diesels emit far less toxic carbon monixide (CO) and somewhat less unburned hydrocarbons (HC) than comparable gasoline engines, and oxides of nitrogen (NO_x) have long been considered to be about the same from both types of engines when compared on the same basis.

In the United States, practically all automotive diesels are used in truck and bus applications in intercity and intracity service. Only one diesel-powered passenger car is in commercial use in this country, and it is the Mercedes 220 D, four-cylinder, naturally aspirated diesel engine. Though several tests have been made of the 220 D vehicle, the tests were done by privately owned companies and the results have not been made public to date. Also, it is understood that exhaust odor evaluations have not been made.

The Mercedes 220 diesel is not subject to Federal regulations of exhaust emissions since the current light-duty regulations apply only to gasoline-powered vehicles. Its sister vehicle, powered by the four-cylinder gasoline engine, has been subject to nationwide Federal certification and exhaust emission control since 1968. Only a limited number of tests have been run with the gasoline-powered vehicle using the new LA-4 Federal driving method and

constant volume sampling (CVS) procedure required in 1972. To our knowledge, no data have been reported for the 220 D operated on the 1972 Federal procedure.

This project is an attempt to obtain limited data with both types of engines in comparable vehicles. It was authorized by Modification 3, dated April 16, 1971, to Contract CPA 70-44. This basic contract was for continued studies of public opinion to diesel exhaust odor and was titled, "Public Response to Diesel Engine Exhaust Odors." The project was completed with a surplus which was used to perform this project. It was under the direction of Dr. Joe Somers, Project Officer, Environmental Protection Agency, Air Pollution Control Office, 5 Research Drive, Ann Arbor, Michigan. Karl Springer served as the SwRI Project Leader with gasoline studies conducted by Clifford Tyree and diesel studies supervised by John Storment. It was identified within SwRI as Project 11-2794-01, started in early May 1971, and was completed 1 month later.

II. OBJECTIVE

The objective of this project was to determine emissions from Mercedes automobiles powered by a four-cylinder diesel and a four-cylinder Otto (gasoline-fueled) Mercedes engine. In addition to measuring odor, smoke, and gaseous emissions from the diesel-powered car using methods developed for heavy-duty diesel trucks and buses, comparative tests of the gasoline and diesel vehicles were made using the 1972 Federal Emissions Test Procedure for CO, HC, and NO.

III. TEST PLAN

To meet the objective of this project, a test plan was prepared which called for an extensive series of tests on the diesel-powered car. Odor measurements were made after a brief familiarization period with the vehicle and a map of conditions employed. The engine has a rated speed of 4200 rpm and a peak torque speed of 2400 rpm. For Engine Manufacturers Association (EMA) gaseous emissions and Federal smoke tests, the intermediate speed is defined as peak torque or 60% of rated, whichever is higher. Intermediate speed was 2520, rounded off to 2500 rpm for simplicity. Loads evaluated included zero, one-half and full power at 4200 rpm and 2500 rpm and low idle of 700 rpm (no load) in triplicate in a random order. One-half load was defined at a fuel rate midway between the fuel rates at full and no load (transmission in neutral). Gaseous emissions were also taken during these steady-state, speed-load odor maps. Measurements included HC, CO, NO, CO_2, acrolein, aliphatic aldehydes, and formaldehyde. These seven conditions, in triplicate (21 runs), were repeated on three consecutive mornings.

In the afternoons, an attempt was made to simulate transient-type vehicle operation. This was particularly difficult as the dynamometer employed for odor work was designed for use with larger vehicles such as trucks and buses. Simulation of accelerations and decelerations is best accomplished using inertia flywheels and the smallest available on the existing machine adjacent to the odor laboratory is for 16,000-lb vehicle weight.

The Mercedes requires only 3500 lb of simulation. Adequate test simulation was achieved by preloading the water-brake chassis dynamometer, which

follows the "q" curve of hp vs mph similar to that of cars on the road. By presetting the absorber load and carefully selecting operating speeds (mph), an acceleration after upshift, a deceleration after a cruise, and an acceleration after idle, from rest, was run. These three transients were replicated in random order four times for a total of twelve transients per afternoon. No gaseous emissions were taken during transient operation.

Smoke tests consisted of simulating the Federal Smoke Test Cycle, per June 4, 1968, and November 10, 1970, Federal Register (Refs. 1 and 2, respectively) normally employed with heavy-duty size vehicles (above 6000-lb GVW). This procedure involves an acceleration from 200 rpm above low idle (simulated "low" gear acceleration) followed by another acceleration from intermediate speed to near rated speed (simulated acceleration in a "high" gear) and concluded by a lugdown from rated to intermediate speed at maximum power. As discussed earlier, rated speed was 4200 and intermediate was 2520 rpm.

The Federal procedure is stipulated to be done on an engine dynamometer, but a quite satisfactory simulation can be accomplished by a chassis-operated engine using suitable chassis dynamometer and inertia flywheels. A 60-truck diesel surveillance fleet has demonstrated the ability of chassis simulation to achieve realistic and repeatable smoke-engine rpm traces. The acceleration-lugdown sequence is repeated twice during a run, and smoke tests were run four times.

In addition to the simulated Federal smoke test, a power and smoke curve was run at maximum power from 4200 rpm to 2600 rpm in 400-rpm increments.

This procedure involves a stairstep operation in which each point is held longer than during the lugdown of the Federal cycle. Also, the speed range is broader.

Cyclic-type gaseous emissions were obtained using a procedure proposed by the Engine Manufacturers Association (Ref. 3) to the California Air Resources Board (ARB) for diesel-powered trucks and buses. The ARB has since adopted this procedure (Ref. 4) and the EPA has permitted the ARB to promulgate standards during recent waiver proceedings (Ref. 4). The California limits for 1973 are 16 g of HC + NO_2 per bhp-hr and 40 g of CO per bhp-hr. In 1975, these are reduced to 5 and 25, respectively. The limits are based on a test procedure, described in References 3 and 5, which is a 13-mode stairstep speed and load map of the engine. Briefly, the procedure starts with low idle, then 0, 25, 50, 75, and 100% load at intermediate speed (2520 for 220 D) followed by low idle. Then speed is increased to rated (4200 for 220 D) at 100% load with decrease to 75, 50, 25%, and no load. Another idle is then run. Please refer to Reference 5 for further details and for the basis of development.

The final series of tests with the diesel were made using the new 1972 Federal Test Procedure (Ref. 2) which incorporates the LA-4 driving schedule and CVS-analysis method. One major potential complication which arose in utilizing this system with the diesel was the preciseness of the hydrocarbon measurements. Diesel exhaust hydrocarbons are predominately higher molecular weight, higher boiling point, and more easily condensed from their mainly gaseous state on exit of the combustion chamber than the hydrocarbons from the gasoline-fueled

spark-ignition engine. The instruments and apparatus used will be described in a later section.

The gasoline-powered Mercedes was tested using the 1972 Federal Test method for CO, NO, and HC in accord with the November 10, 1970 Federal Register (Ref. 2). In addition, formaldehyde, aliphatic aldehydes, and acrolein were measured using the remainder of the CVS bag of diluted exhaust. The test plan for the gasoline and diesel cars included replicate cold-start tests on as identical a basis as possible to permit comparison of the results.

IV. TEST EQUIPMENT INSTRUMENTS AND APPARATUS

In keeping with the limited scope of this project and final report, the equipment, instruments, and experimental apparatus employed will be mentioned with reference to more detailed descriptions both in previous final reports and the open literature.

A. Odor and Related Instrumental-Wet Chemical Analysis

The PHS quality intensity (QI) or Turk kit method of evaluation of dilute samples of diesel exhaust odor (Ref. 6) was employed to express odor judgments by the trained ten-person SwRI odor panel. The kit includes an overall "D" odor in steps of 1 through 12, 12 being strongest, that is made of four sub-odors or qualities. These comprise burnt smoky "B", oily "O", aromatic "A", and pungent "P" qualities each in a 1 through 4 intensity series, 4 being strongest. Special odor sampling, dilution, and presentation facilities for diesel odor research were developed about 5 years ago using design criteria obtained in field studies of atmospheric dilution of bus and truck exhaust.

Horizontal exhaust at bumper height from a city bus was found to be diluted to a minimum reasonable level of 100:1 before being experienced by an observer. This dilution level was used in the study of the Mercedes 220 D. References 7 and 8 describe the odor facility and References 7 through 9 describe the development of procedures and operating conditions for research purposes.

Several years ago, Nondispersive Infrared (NDIR) and Flame Ionization Analysis (FIA) and wet chemical analysis were added to measure gaseous materials at the same time. These measurements assisted in determining control device effectiveness and in correlating odor ratings to routine exhaust analysis. In brief, NDIR was employed for CO, NO, and CO_2 and the SwRI high temperature (375° F) analyzer (Ref. 10) was used for exhaust hydrocarbon measurement. The chromotropic acid method for formaldehyde, 3-methyl-2-benzylthiozolone hydrazine (MBTH) method for aliphatic aldehydes, and the 4-hexylresorcinal method for acrolein, all of which are wet chemical methods, were employed. These are described somewhat in Reference 11. Procedures for odor measurement, i.e., method and theory of operation, were described in the test plan.

B. Smoke

The PHS full-flow light-extinction smokemeter, featured in the Federal Smoke Test and regulations for diesel engines in heavy-duty vehicles, was used exclusively to measure smoke from the Mercedes 220 D. The smokemeter is described in both June 4, 1968 (Ref. 1) and November 10, 1970 (Ref. 2) Federal Register as well as several other publications. It is quite responsive to transient smoke behavior and is well within the ±1% opacity accuracy. The chassis

dynamometer utilized was similar to the unit used for odor tests but had lower inertia simulation. The water brake of the Clayton CT-200 dynamometer is 200-hp capacity. This, plus inertia flywheels, made simulation of the Federal test procedure possible.

C. Cyclic Gaseous Emissions

The chassis alternative of the EMA procedure requires a 39-min speed-load map of 13 modes, at 3 min per mode. In addition to CO, NO by NDIR, and HC by heated FIA, fuel rate must be measured continuously (according to SAE recommended procedure V177). A Flo-Tron system was used to measure the net fuel consumption of the engine, which, in turn, enabled the use of manufacturer's curves for inlet air rate and engine flywheel horsepower. Part IV of the Diesel Final Report to EPA (Ref. 12) includes a section on development of this cyclic procedure and copies of the EMA 13-mode procedure, Draft No. 7, and the California ARB procedure which is essentially Draft 7 of the EMA proposal.

D. 1972 Federal Test Procedure--Light-Duty Vehicles

This procedure is described in the November 10, 1970, Federal Register (Ref. 2) and specifies the use of the LA-4 driving schedule. The exhaust is sampled and diluted continuously during the 23-min test by a CVS. The need to obtain emissions from the diesel and gasoline vehicle by as identical a procedure as possible prompted selection of a relatively low CVS flow rate, a nominal 150 CFM. This flow rate was selected to permit adequate measurement of the expected low emissions of CO and HC from the diesel, yet maintain CVS blower inlet air temperature within specification.

The Mercedes 220 D engine was tested using the same chassis dynamometer horsepower and inertia simulation settings. The same driving aid and preprinted chart paper was used. Hydrocarbons were measured in the usual way with the normal flame ionization analyzer used with diluted gasoline exhaust. To determine the possible loss of hydrocarbons due to condensation and hang-up on sampling system heat exchanger and Tedlar plastic bags, some experiments were made under selected steady state conditions with the SwRI high temperature HC analyzer at the inlet to the heat exchanger and at the inlet to the Roots CVS blower at the normal sampling point and from a diluted bag at various periods of time after collection.

The results of these experiments, made at several constant speeds and loads at varying levels of hydrocarbon output, resulted in serious concern about the reliability and precision of HC measurements when the exhaust is handled in the normal way with the constant volume sampler. It should suffice to say that the heat exchanger and other sampling components, including the plastic bag, in contact with the dilute exhaust serve to trap-out many of the high boiling temperature high molecular weight hydrocarbons. Condensation of these materials, such as unburned fuel, etc., occurs in a variable way that is somewhat speed and load dependent as well as time and history dependent.

Under the limitations of time and funds for this study, the best method available was to take a sample at the inlet to the Roots CVS blower and transfer it to the SwRI diesel hydrocarbon analyzer, keeping the sample and all sampling components as well as analyzer heated to 375°F. By analyzing a continuous sample throughout the run, the resulting 23-min trace could be time integrated

to give an overall average concentration which could be converted to g/mile. More discussion of this point will be given in Section VII of this report.

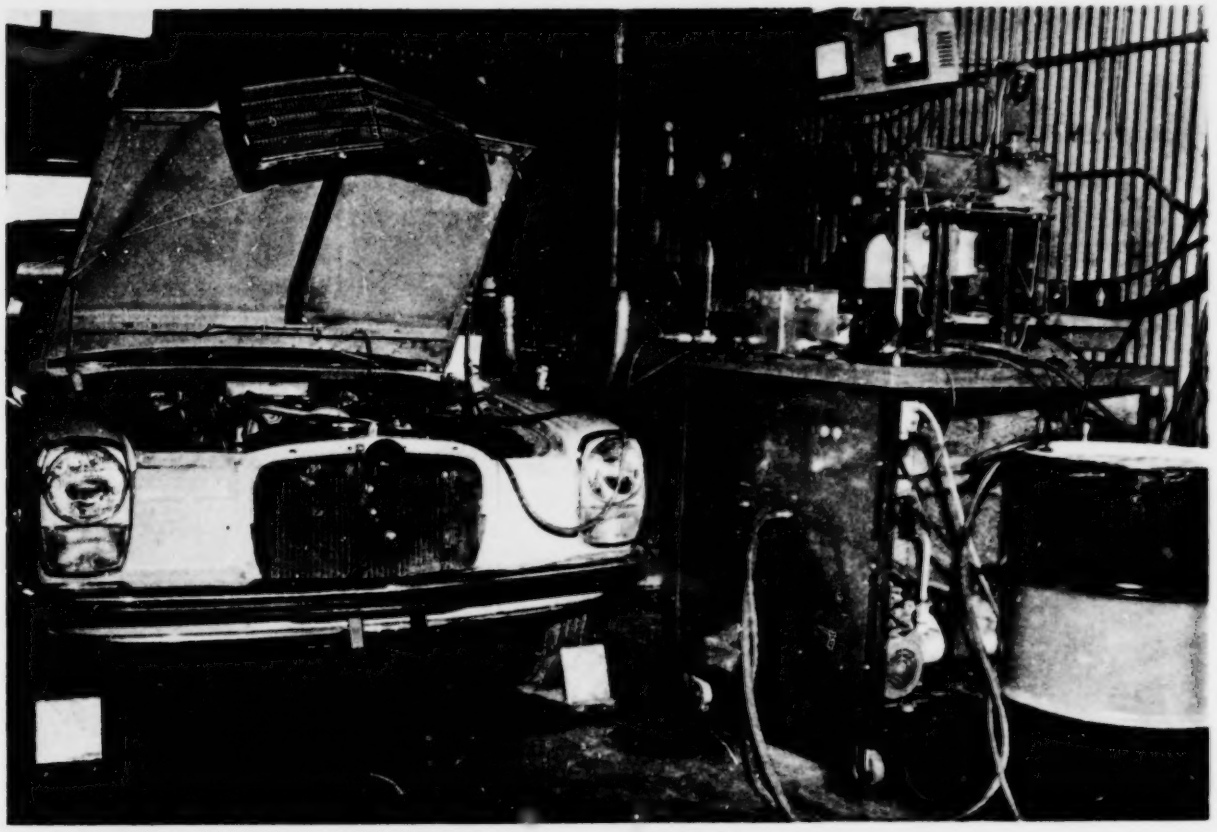
Reference 13, the February 27, 1971, Federal Register, describes the chemiluminescence method for oxides of nitrogen measurement. The newness of this method and the difficulty in obtaining the system in time for this project precluded its use simultaneously with other measurements. Diluted bag exhaust was subjected to NO measurement by NDIR and by electrochemical (Enviro-metrics) methods and NO_x ($NO + NO_2$) by a modified Saltzman syringe method.

Finally, the bag samples were pumped slowly through wet chemistry absorbers for analysis of formaldehyde, aliphatic aldehydes, and acrolein, (three oxygenates), the first two of importance in reactivity and all three related to diesel odor. Chromatropic acid, MBTH, and the 4-hexylresorcinal methods, mentioned earlier, were used in this exploratory part of the project.

V. TEST VEHICLES AND FUELS

The two test vehicles, furnished through the courtesy of Mr. Hans Prykop and Mr. Gerhard Langhans of Mercedes-Benz of North America, are described in Table 1. The 220 D vehicle, vehicle number 12-153636, had 16,450 miles and the 220 gasoline, vehicle number 12-049417, had 16,378 miles when delivered to SwRI. Both vehicles were equipped with four-speed automatic transmission and the engines were in satisfactory running condition.

Figures 1 and 2 are various views of the diesel-powered auto engine prepared for odor and gaseous emissions tests and smoke opacity runs on special SwRI chassis dynamometer facilities. Figure 3 contains two views



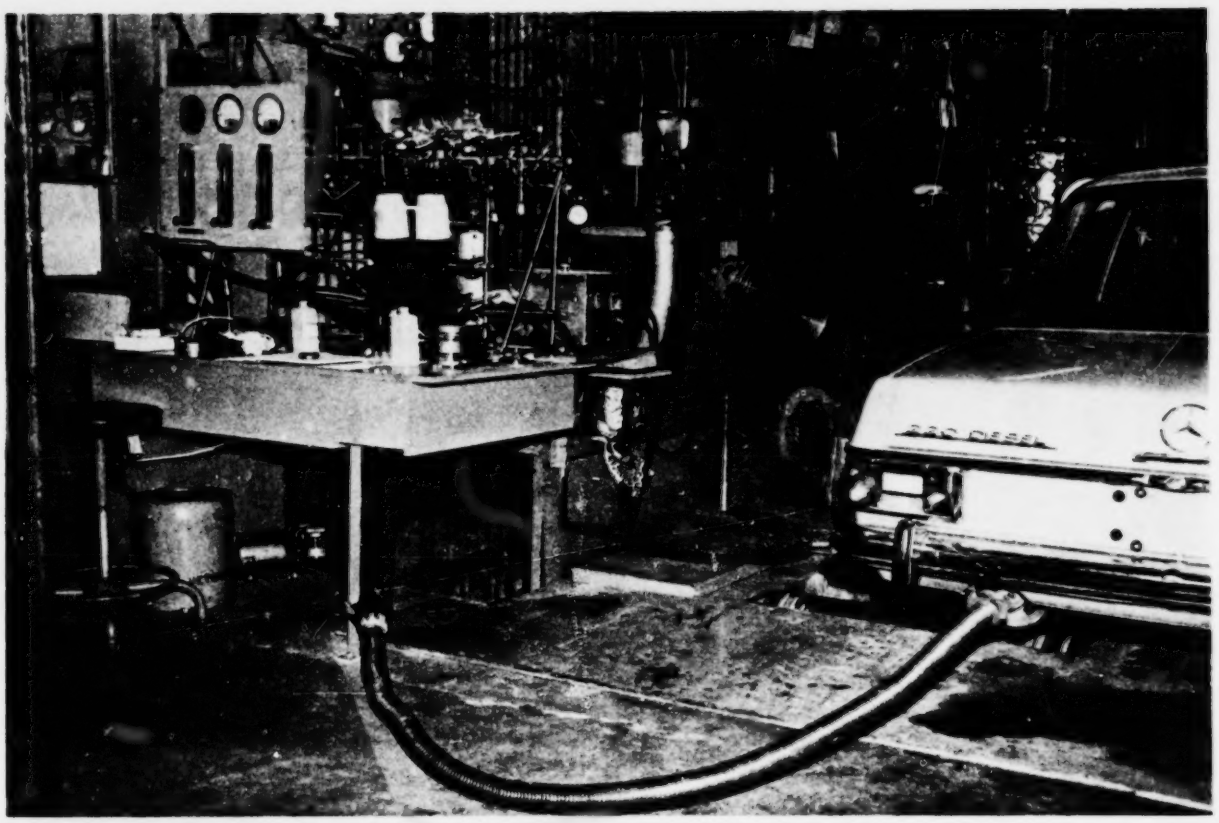


FIGURE 1. ODOR AND GASEOUS EMISSIONS TEST OF MERCEDES 220 DIESEL

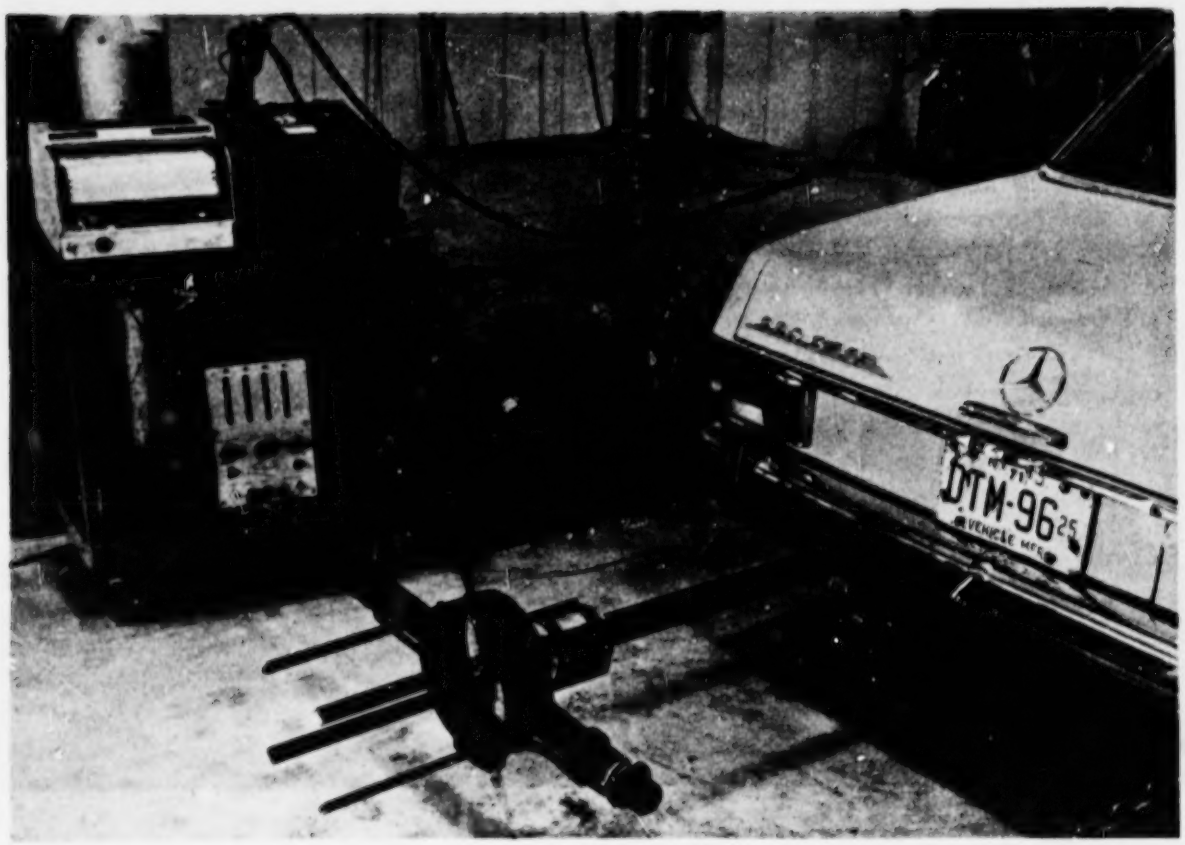


FIGURE 2. EXHAUST SMOKE OPACITY TEST OF MERCEDES 220 DIESEL

FIGURE 3. FEDERAL EMISSIONS TEST OF MERCEDES 220 GASOLINE

TABLE 1. MERCEDES-BENZ

Model	220 D	220
Type of vehicle	Sedan	Sedan
Number of cylinders	4	4
Total piston displacement, cu. in.	134	134
Output SAE, gr hp/rpm	65/4200	116/5000
DIN, PS/ rpm	60/4200	105/4800
Maximum torque SAE, lb-ft/rpm	96/2400	142/3000
Maximum torque DIN, lb-ft/rpm	93/2400	132/2800
Compression ratio	21:1	9:1
Acceleration 0 to 62, miles/sec	28, 1	13, 7
Rear axle ratio	i = 3, 92	i = 3, 92
Maximum speed, mph (approx.)	84	104
Tires	6.95 - 14/ 175 - 14/4 PR	6.95 S 14/ 175 S 14/4 PR
Turning circle radius, ft	35.6	35.6
Fuel tank, U.S. gal.	17.2	17.2
Wheelbase, in.	108.3	108.3
Overall length, in.	184.5	184.5
Overall width, in.	69.7	69.7
Overall height, in.	56.7	56.7
Empty weight, lb	3040	2960

of the Mercedes 220 spark-ignition engine prepared for the 1972 Federal Test Procedure for CO and HC via the CVS method also shown. This dynamometer and CVS were used to test the diesel-powered car also. An inertia simulation equivalent to 3500-lb vehicle weight was used for both vehicles during the 1972 Federal tests.

The gasoline test fuel was obtained under the specifications listed in the November 10, 1970, Federal Register (Ref. 2). Results of an inspection of the fuel are shown in Table 2.

The diesel test fuel conformed to the specifications in the November 10, 1970 Federal Register (Ref. 2) for No. 2 D emissions test fuel. The inspection data for a sample of the fuel used in the diesel tests are listed in Table 3.

TABLE 2. FUEL INSPECTION REPORT FOR EMISSIONS TEST GASOLINE

Item	Specifications
Octane, Research	103.4
Pb (organic), g/U.S. gal.	3.27
Distillation range	
IBP, °F	88
10% point, °F	127
50% point, °F	220
90% point, °F	305
EP, °F	340
Sulfur, wt %	0.004
Phosphorus, theory	0.0
RVP, lb	9.1
Hydrocarbon composition	
Olefins, %	0.4
Aromatics, %	27.3
Saturates	Remainder

TABLE 3. DIESEL EMISSIONS TEST FUEL INSPECTION DATA

Item	Specifications
Fuel Designation	DF-2
Cetane Number	44.9
Distillation	
IBP, °F	357
10% point, °F	418
50% point, °F	488
90% point, °F	559
EP, °F	600
Specific Gravity, °API at 60°F	33.9
Total Sulfur, %	0.25
Hydrocarbon composition, %	
Aromatics, %	30.8
Paraffins, Napthenes, Olefins	Remainder
Flash Point, °F	155
Viscosity, centistokes at 100°F	2.50

VI. DIESEL EMISSIONS RESULTS

The results of the extensive tests of the single Mercedes 220 D vehicle will be discussed topically for odor and emissions, smoke, and then cyclic gaseous emissions.

A. Odor and Emissions Results

Table 4 summarizes the 3 days of odor evaluations listed in detail in Appendix A of this report. The "D", "B", "O", "A", and "P" ratings represent the overall panel three-run average. Though each day's runs were made in random order, the day-to-day repeatability and run-to-run repeatability per Appendix A data were as good as could be expected. Various plots of the odor data have been made to try and understand the odor-ratings behavior versus load and speed to no great avail. The behavior of decreasing odor intensity with an increase in power at 2500 rpm was counter to the behavior at 4200 rpm. At rated speed, odor was highest at half power and this characteristic is generally the reverse of most diesel engines previously tested for which minimum odor usually occurs at midpower. Low-idle operation did not produce a particularly high odor level relative to high-idle operation at 2500 rpm, for example.

Transient odor evaluations revealed the deceleration after cruise to be significant odor producing condition. The average D rating of 6.8 for deceleration is as high or higher than the D intensities measured for uncontrolled city buses powered by two-cycle stroke diesel engines, one of the most intense, if not the most intense, condition known. In general, the odor does not resemble any specific odor previously encountered from two-stroke, four-stroke,

TABLE 4. ODOR SUMMARY--MERCEDES 220 D EVALUATION

Condition	Load	Date	"D" Composite	"B" Burnt	"O" Oily	"A" Aromatic	"P" Pungent
2500 rpm 34 mph	0	5/10/71	5.6	2.0	1.3	1.1	1.2
		5/11/71	6.3	2.0	1.6	1.0	1.6
		5/12/71	6.1	1.9	1.3	1.1	1.6
		Average	6.0	2.0	1.4	1.1	1.5
2500 rpm 34 mph	1/2	5/10/71	3.9	1.2	1.1	0.9	0.6
		5/11/71	4.0	1.1	1.0	0.9	0.8
		5/12/71	3.4	1.1	1.0	0.7	0.7
		Average	3.8	1.1	1.0	0.8	0.7
2500 rpm 34 mph	Full	5/10/71	4.3	1.3	1.1	1.1	0.7
		5/11/71	3.2	1.0	1.0	0.8	0.4
		5/12/71	4.4	1.4	1.0	0.8	1.2
		Average	4.0	1.2	1.0	0.9	0.8
4200 rpm 29 mph	0	5/10/71	4.7	1.6	1.1	1.1	1.0
		5/11/71	4.6	1.3	1.1	0.9	1.1
		5/12/71	3.9	1.1	1.0	0.9	0.9
		Average	4.4	1.3	1.1	1.0	1.0
4200 rpm 29 mph	1/2	5/10/71	6.2	2.0	1.3	1.1	1.5
		5/11/71	6.1	2.1	1.5	1.0	1.6
		5/12/71	6.1	2.2	1.2	1.1	1.7
		Average	6.1	2.1	1.3	1.1	1.6
4200 rpm 29 mph	Full	5/10/71	5.0	1.8	1.1	1.1	1.0
		5/11/71	5.9	1.9	1.4	1.1	1.3
		5/12/71	5.7	1.9	1.3	1.0	1.5
		Average	5.5	1.9	1.3	1.1	1.3
Idle		5/10/71	4.0	1.1	1.1	1.0	0.9
		5/11/71	4.0	1.2	1.0	1.0	0.8
		5/12/71	3.8	1.1	1.0	0.9	0.8
		Average	3.9	1.1	1.0	1.0	0.8
Idle Acceleration		5/10/71	4.8	1.7	1.0	1.0	1.0
		5/11/71	4.3	1.2	1.1	1.0	1.0
		5/12/71	4.3	1.3	1.0	1.0	0.8
		Average	4.5	1.4	1.0	1.0	0.9
Acceleration		5/10/71	5.3	2.0	1.3	1.0	1.2
		5/11/71	5.3	1.8	1.1	1.0	1.3
		5/12/71	5.1	1.6	1.1	1.1	1.1
		Average	5.2	1.8	1.2	1.0	1.2
Deceleration		5/10/71	7.0	2.2	1.7	1.2	1.9
		5/11/71	6.4	2.0	1.5	1.2	1.7
		5/12/71	6.9	2.1	1.8	1.1	1.9
		Average	6.8	2.1	1.7	1.2	1.8

prechamber, open-chamber, turbocharged, or naturally aspirated diesel engines previously tested.

Though many of the odor strengths are similar to uncontrolled buses, the character of the odor was somewhat different. The pungent quality was quite noticeable as indicated by the higher "P" ratings than previous. Less kerosene odor, or unburned hot-fuel smell was noticed, but, when combined with the penetrating, pungent odor, there resulted a type of odor difficult to describe in terms of previous experience. The odor evaluated was judged to be very typical of that encountered by the writer on West German autobahns and in urban traffic, including, among other sources, a number of diesel-powered Mercedes cars. The odor presented to the panel at 100:1 dilution was termed realistic of traffic levels encountered.

Simultaneously with the steady-state odor evaluations, exhaust emissions of HC, CO, NO, aldehydes, formaldehyde, and acrolein were measured. These measurements, listed in Appendix A, Tables A4 through A6, are summarized on Table 5 of the text and correspond to the odor conditions, etc., listed on Table 4. The as-measured concentrations of Table 5 for each day's operation are tabulated and an overall average obtained. Day-to-day repeatability of HC, CO, and NO seemed satisfactory except for HC at 4200 rpm and 1/2 load. Wet chemical measurements were less repeatable than usual under certain conditions, and this was a reflection of the run-to-run difficulties encountered. Cyclic emissions results, to be discussed later, exhibited less than the usually good repeatability of diesels previously tested. This engine, though operating

TABLE 5. EMISSIONS OBTAINED SIMULTANEOUSLY WITH ODOR RATINGS--MERCEDES 220 D EVALUATION

Condition	Load	Date	HC, ppm	CO, ppm	NO, ppm	Acrolein, ppm	Formaldehyde, ppm	Aliphatic Aldehydes, ppm
2500 rpm 34 mph	0	5/10/71	1004	727	73	7.5	17.4	28.0
		5/11/71	1063	695	69	10.6	16.2	30.3
		5/12/71	873	718	93	5.0	12.6	26.3
		Average	980	713	78	7.7	15.4	28.2
2500 rpm 34 mph	1/2	5/10/71	59	182	348	0.6	19.0	25.6
		5/11/71	75	242	329	2.8	17.8	24.5
		5/12/71	79	268	341	0.7	8.7	13.1
		Average	71	231	339	1.4	15.2	21.1
2500 rpm 34 mph	Full	5/10/71	58	281	467	1.1	13.1	12.1
		5/11/71	67	177	504	0.9	6.5	10.1
		5/12/71	67	169	545	1.1	21.5	20.2
		Average	64	209	505	1.0	13.7	14.1
4200 rpm 29 mph	0	5/10/71	67	329	221	1.7	9.4	10.8
		5/11/71	96	359	204	1.0	8.0	12.1
		5/12/71	104	355	246	0.8	6.4	14.9
		Average	89	348	224	1.2	7.9	12.6
4200 rpm 29 mph	1/2	5/10/71	396	1076	536	3.5	23.4	34.3
		5/11/71	933	1200	504	9.0	15.4	36.2
		5/12/71	888	1189	544	6.3	21.2	34.9
		Average	730	1155	528	6.3	20.0	35.1
4200 rpm 29 mph	Full	5/10/71	59	1357	553	1.1	22.8	29.2
		5/11/71	71	746	603	1.5	29.5	27.9
		5/12/71	50	801	638	1.9	12.7	18.1
		Average	60	968	598	1.5	21.7	25.1
Idle		5/10/71	155	204	118	2.2	12.5	21.0
		5/11/71	79	156	122	0.9	11.7	17.5
		5/12/71	80	143	132	1.8	11.9	18.6
		Average	105	168	124	1.6	12.0	19.0

satisfactorily, just lacked the run-to-run and day-to-day stability in operation noted over the past several years of work with larger truck and bus diesels.

With regard to emissions behavior, it is evident from Table 5 that HC was substantially higher at no load and 2500 rpm and at 1/2 load and 4200 rpm than at the other loads investigated at both speeds. Low idle was not a big contributor of HC. Previous studies of instrumental correlation to odor-panel ratings has pointed to exhaust HC as an important predictor of odor intensity. The high levels of odor noted correspond directly to the high concentrations of unburned HC in the exhaust. Acrolein has also been found to be a good predictor of odor strength and the same correlation to high odor at no load and 2500 rpm and at 1/2 load and 4200 rpm was found. Aliphatic aldehydes, another indicator of odor found from the extensive previous studies, likewise corresponds nicely to odor panel ratings, especially at 4200 rpm.

With regard to magnitude, the HC levels measured at no load and 2500 rpm (980 ppm C) and 1/2 load and 4200 rpm (739 ppm C) are reminiscent of a two-stroke city bus engine with old crown valve injectors at either no load and high speed or at very heavy load. The remainder of the steady-state HC emissions are more comparable to two-stroke city bus or truck engines with N or LSN injectors or optimized naturally aspirated and turbocharged open chamber or prechamber engines. CO conditions are higher than many four-stroke diesel engines. The magnitudes are different at the same power levels for each speed and this is not explainable from this limited study. Apparently 1/2 load at 4200 rpm is an off-design point for HC, CO, and odor along with acrolein, formaldehyde, and aliphatic aldehydes. In general, the oxgenates were similar

concentration to many two-stroke in-powered city buses equipped with S injectors. Oxides of nitrogen were low and their increase with load seems reasonable, though less than that experienced with other well-designed engines.

B. Smoke and Cyclic Emissions

Table 6 lists in summary form the results of the simulated Federal smoke (chassis-dynamometer version) tests. In all, four runs were made, each consisting of three replications, and the chart readings for each run are included in Appendix B of this report. A sample acceleration lugdown smoke trace is shown as Figure 4 to illustrate smoke behavior versus engine rpm and time. The acceleration or "a" factor average of 10.8% and lugdown or "b" factor average of 9.4% opacity may be compared to the Federal limits of 40 and 20% opacity. An exhaust opacity of 10% represents noticeable smoke and is slightly lighter than a Ringelmann 1 rating. An opacity of 3 to 4% is the visibility limit for exhaust smoke by the PHS smokemeter.

The power-curve smoke-test results are listed on Table 6 for maximum power operation at 4200, 3800, 3400, 3000, and 2600 rpm. The smoke readings essentially confirm the lugdown ratings made during the Federal test. It should be mentioned that the smoke from this engine was measured several weeks later, after additional tests were made by the 1972 procedure for gaseous emissions involving the CVS and LA-4 driving route. The objective of the later smoke tests was to investigate the effect of two candidate fuel additives on emissions, and was conducted as part (Part V) of the long-range investigation of diesel odor and smoke. After operating on the first additive

TABLE 6. SUMMARY OF SMOKE AND EMA CYCLIC EMISSIONS TESTS
MERCEDES 220 D EVALUATION

Results of Federal Smoke Tests

	PHS Smoke Opacity, %				
	Run 1	Run 2	Run 3	Run 4	Average
"a" Factor	10.1	11.1	11.5	10.7	10.8
"b" Factor	8.5	10.3	10.1	8.8	9.4

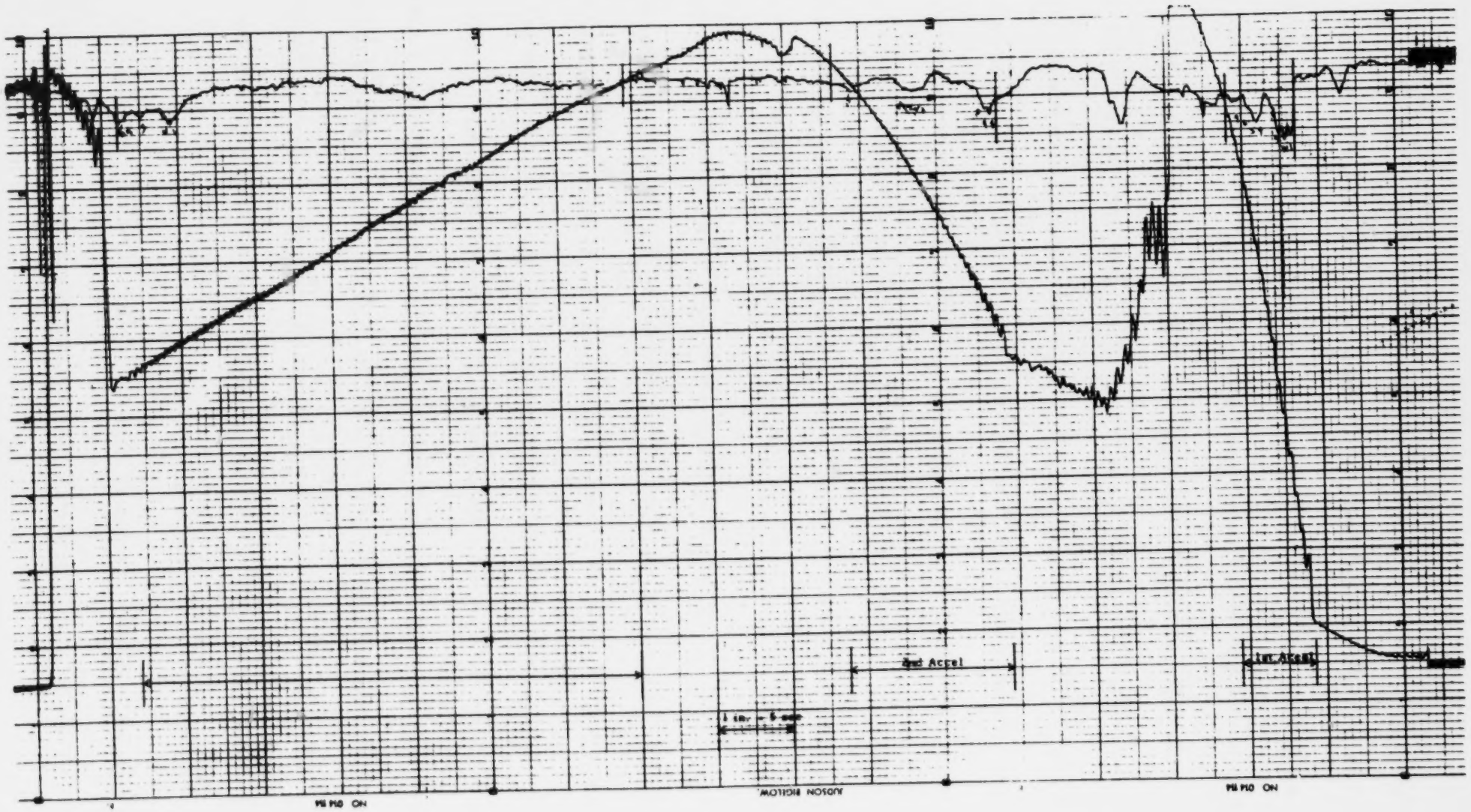
Results of Power Curve--Smoke Tests

	PHS Smoke Opacity, %					
RPM	Run 1	Run 2	Run 3	Run 4	Average	Power*
4200	8.0	8.0	7.5	10.0	8.4	32
3800	7.2	7.5	6.8	11.0	8.1	35
3400	8.0	7.2	6.6	6.2	7.0	34
3000	6.5	6.6	5.3	5.0	5.8	31
2600†	10.0	9.3	7.4	6.5	8.3	26

*Rear wheel horsepower, observed.
†Downshifting of the automatic transmission prevented power readings below 2600 engine rpm.

Results of EMA 13-mode, 39-min
Gaseous Emissions Tests, g/bhp-hr

	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Average
HC	1.26	1.25	1.30	1.30	1.16	1.06	1.22
CO	4.97	4.65	4.94	4.22	4.81	4.29	4.65
NO	3.57	3.64	3.50	3.87	4.20	4.08	3.81
NO as NO_2	5.47	5.58	5.37	5.93	6.44	6.26	5.84
HC + NO_2	6.73	6.83	6.67	7.23	7.60	7.32	7.06



Date: 5-17-71
Chart Speed: 12 in./minute

100% Chart - 4500 rpm
100% Chart - 100% Opacity

Start/End First Accel: 20/84%
Start/End Second Accel: 56/93%
Start/End Lugdown: 93/56%

FIGURE 4. TYPICAL FEDERAL CYCLE SMOKE-ENGINE SPEED RECORDING
MERCEDES 220 D EVALUATION

treated fuel, both a DF-2 commercial diesel fuel and the DF-2 emissions-test fuel, described earlier, were used to start the back-to-back test series.

Smoke during the Federal test and the power curve test using untreated fuel was approximately half of that reported in Table 6. The rear wheel power output was essentially the same, as was fuel rate into the engine. Additional diagnostic efforts failed to indicate why the engine produced less smoke. Further tests with the untreated base DF-2 fuel showed slightly lower odor with other emissions of HC, CO, and NO about the same. It could have been that one injector was partially malfunctioning during the initial test series and cleared itself during the LA-4 driving cycle emission tests. The results of the fuel additive tests will be reported in a bimonthly report under Contract PH 22-68-23 to Mr. Ralph Stahman of EPA, the Project Officer.

At the bottom of Table 6 are the results of the cyclic emissions tests performed using the chassis version of the EMA-California ARB test procedure. In all, six runs were made, three each on 2 days, to establish satisfactorily the cyclic emissions behavior of this heretofore untested engine. Though the run-to-run and mode-by-mode repeatability at certain modes was inferior to that achieved during tests of over 50 diesel-powered trucks and buses under a diesel surveillance project (Contract EHS 70-109), the variations seemed to self-compensate and result in apparently good overall run-to-run repeatability. For mode concentrations and emissions calculations, please refer to the cyclic data included in Appendix B, Tables B5 and B6.

The average of 1.22 HC g per bhp-hr is similar to slightly higher than many of the diesels previously tested. In combination with the brake specific

NO, in terms of NO_2, the average of 7.06 g HC + NO_2 per bhp-hr is well within the 16-g standard for 1973 in California, but in excess of the 5-g limit set for 1975 by the ARB. Many truck and bus engines tested to date are double this Mercedes 220 D engine average of 7.06. Nitric oxide is particularly low with this Mercedes 220 D and is the major reason for the difference. Whether this engine could be modified to meet 1975 California standards is not known. It is a mute point, however, since the diesel regulations apply to heavy-duty applications of above 6,000-lb gross vehicle weight. CO of 4.65 g per bhp-hr is similar to that from many other diesels and is well below the 40- and 25-g limits set by the California ARB as these limits are intended for the gasoline-powered truck and bus (heavy-duty).

There are many analyses that can be made of the cyclic data contained on Tables B5 and B6. Two methods are to compute grams of emissions per hour and per pound of fuel consumed; then plot these values versus engine load or power level for both rated and intermediate speeds. This is done in Figures 5 and 6 for grams per hour and grams per pound of fuel consumed, respectively. The data are listed on Table B7. The somewhat peculiar behavior of HC (at no load and 2500 rpm and at 1/2 load and 4200 rpm) mentioned earlier and CO is shown by both figures. As an example of further analysis of the data on Figure 6, emission impact values could be computed if the amount of fuel consumed overall at various load settings was known or estimated.

In summary of the diesel odor, smoke, and cyclic emissions tests, it can be said for the vehicle tested that odor under certain driving conditions was as intense as old-style S injector-equipped city buses powered by two-stroke

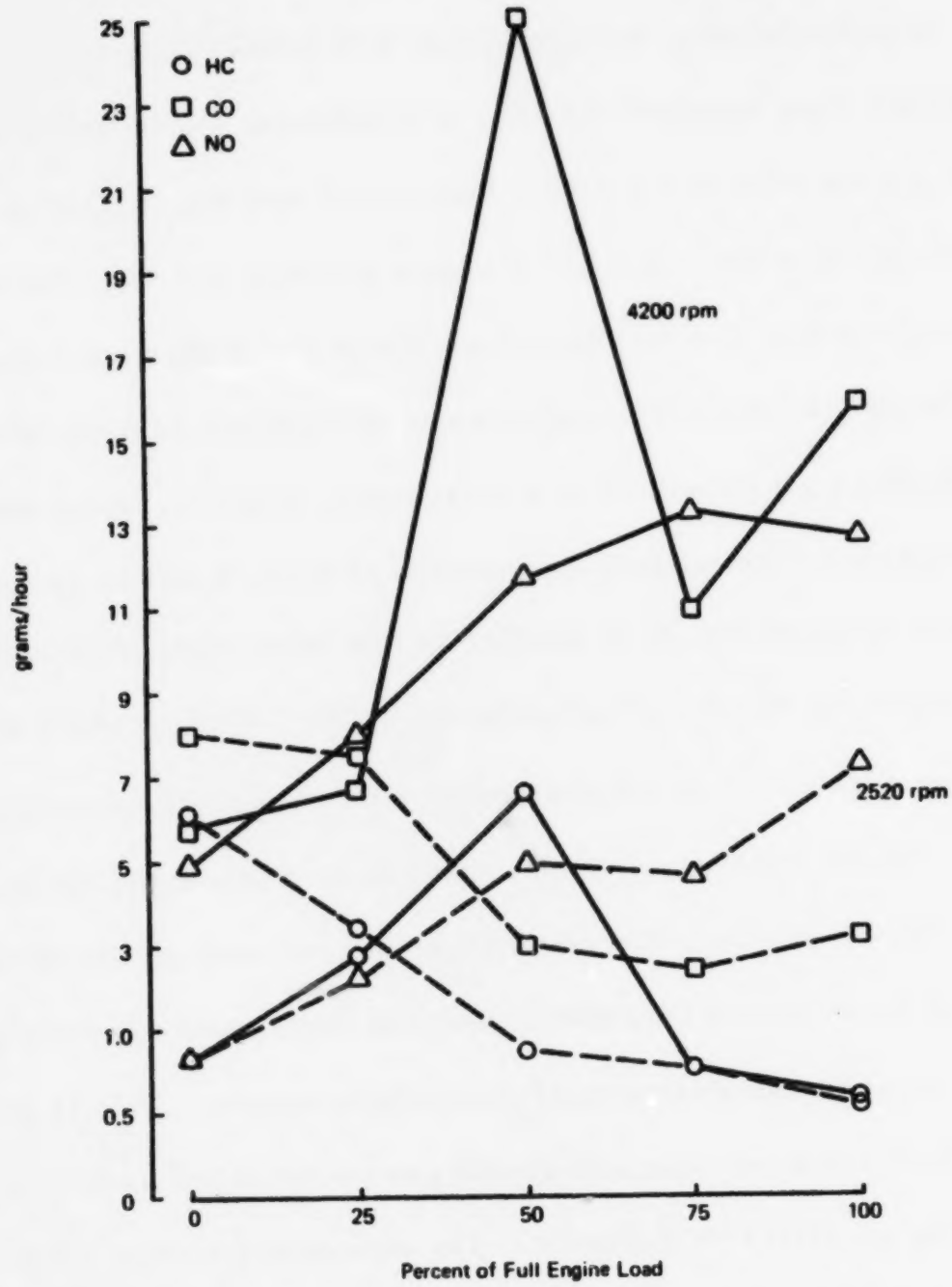


FIGURE 5. AVERAGE GRAMS OF HC, CO, AND NO PER HOUR--MERCEDES 220 D

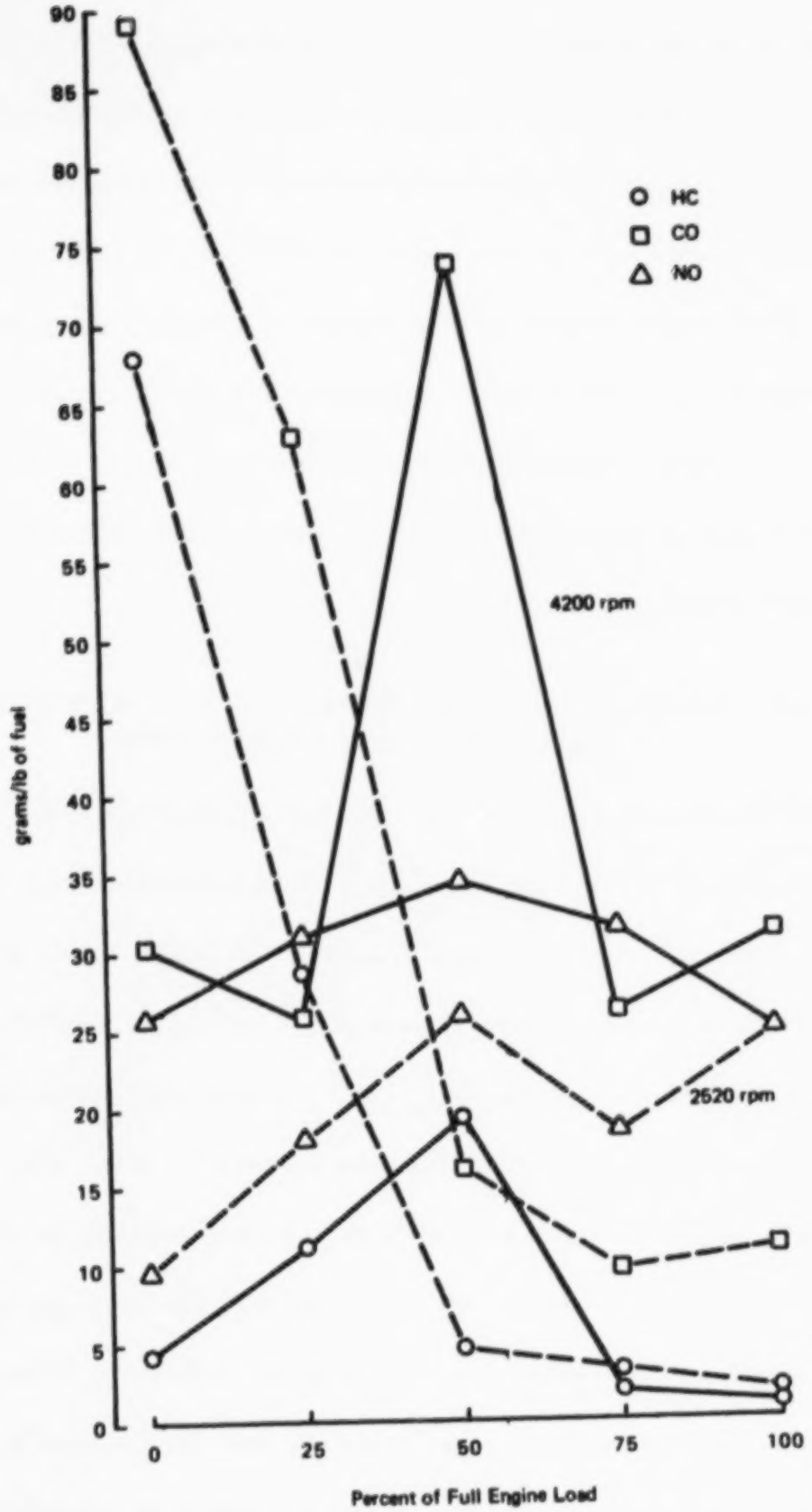


FIGURE 6. AVERAGE GRAMS OF HC, CO, AND NO PER LB OF FUEL--MERCEDES 220 D

engines with a more penetrating, yet less kerosene characteristic, odor quality. HC, acrolein, and aldehydes seemed to correlate well with odor ratings, and they too were indicative of an old-style diesel bus under intense odor conditions. Federal cycle smoke was on the order of 10% (both "a" and "b" factor), a noticeable level while relatively low oxides of nitrogen were responsible for the respectable 7 g of HC + NO_2 obtained during the 13-mode California ARB-EMA test procedure. Additional diesel tests were made on the LA-4 driving schedule and will be reported in the next section to facilitate comparison to the Mercedes 220 gasoline results.

VII. GASOLINE AND DIESEL RESULTS, 1972 FEDERAL EMISSIONS TEST PROCEDURE

This section contains results for both gasoline and diesel Mercedes tests by the new 1972 Federal Light-Duty Exhaust Emissions Test Procedure. The CVS and the LA-4 driving schedule were utilized in this procedure, designed to measure true mass emissions of vehicles below 6,000-lb GVW. Table 7 lists the HC, CO, NO, NO_x, and several oxygenates in terms of grams per mile. Four runs were made and the results for each run, made on a separate day, are listed and averaged to indicate something of the test repeatability. The four-run average HC was 2.68 and the average CO was 32.34 g per mile. Both contaminates are specified in Reference 2 for 1972 model year light-duty at 3.4 and 39 g per mile HC and CO, respectively.

Oxides of nitrogen are specified for control to a maximum of 3 g of NO_x as NO_2 per mile starting with 1973 model year using a chemiluminescence type NO-NO_x instrument. Such an instrument was not available until some time

TABLE 7. MERCEDES 220 GASOLINE 1972 FEDERAL TEST RESULTS
(All Values in Grams/Mile)

		Run No. 1 5/19/71	Run No. 2 5/20/71	Run No. 3 5/21/71	Run No. 4 5/22/71	Average
HC,	FIA	2.97	2.65	2.88	2.23	2.68
CO,	NDIR	30.09	32.99	34.61	29.66	32.34
	The following not specified for 1972					
NO	NDIR	2.47	1.90	1.85	2.22	2.11
(as NO)	Electrochem*	3.08	2.49	2.96	2.35	2.72
	Chemilum†					0.91
NO_x	Saltzman‡	3.89	4.13	3.16	2.92	3.53
(as NO_2)	Chemilum					3.62
Formaldehyde		0.074	0.085	0.059	0.083	0.075
Aliphatic Aldehydes (as formaldehyde)		0.072	0.101	0.065	0.091	0.082
Acrolein		0.042	0.064	0.066	0.066	0.060

*Envirometrics Faristor.
†Single run made 6/14/71 with new Thermo Electron Instrument.
‡Modified syringe method.

after the planned test series was completed. The instrument, furnished for use in a very high-priority aircraft turbojet emissions project, was available for only a single test of both vehicles. Accordingly, several other techniques, none wholly satisfactory or as specified in the recently published 1973 rule making (Ref. 13), were employed to obtain some data on oxides of nitrogen. NDIR analysis of NO was fairly repeatable, but it is known to understate the NO_x produced (defined as NO + NO_2) due to conversion of NO to NO_2 in the dilute CVS bag with time. An electrochemical, Envirometrics Faristor, instrument was tried to determine NO, NO_2, and NO_x. Only NO was found to be credible and, accordingly, the NO_2 and NO_x data were discarded. The average NO grams per mile value from this analysis was higher than that by NDIR, and this has been the general trend when using these two instruments. A single run, made with a brand new ThermoElectron Company (TECO) chemiluminescence NO-NO_x instrument, still in its checkout stages, resulted in lower than expected NO value of about half that normally found by NDIR, which has been fairly reliable. This single value should be used with much caution because of the newness of the instrument and our inability, due to priority commitments, to perform additional tests. The value is expressed as grams of NO per mile and may be converted to grams of NO_2 per mile by the ratio of molecular weights, 46/30.

Modified Saltzman syringe samples, in duplicate, were also taken of the CVS dilute bag and, like all other measurements, of the background bag. The results are shown on Table 7 with an average 3.53 g per mile of NO_x as NO_2. NO_x by the new TECO on a later run was 3.62 g NO_2 per mile which appears

to be in good agreement with Saltzman results. Again, this is a single run and the results should be used with care.

The three partial oxygenates of formaldehyde, aliphatic aldehydes, and acrolein are listed last on Table 7. The value of these data is uncertain, but they were taken as further exploratory data for possible comparison with the diesel results. These wet chemical procedures required bubbling the bags of exhaust slowly through reagent for subsequent colorimetric analysis. The run-to-run repeatability seems satisfactory in light of the methodology, but comment on the magnitude of the result or its precision cannot be offered.

Table 8 is similar to Table 7 in that it lists emissions results using the 1972 driving procedure and CVS, but Table 8 is for the Mercedes 220 Diesel. As mentioned in a previous section, difficulties were encountered in accurately measuring hydrocarbon concentrations in the dilute diesel exhaust after it was handled by the CVS. Though the heat exchanger acts somewhat as a GC column in adsorbing and desorbing, equilibrium seemed to be achieved after several repeated runs and this effect became secondary in importance to the simple condensation of hydrocarbons in the sample taken at the inlet to the CVS blower. This sample is normally obtained and transferred through 1/4 -in. -dia stainless tubing via a suitable diaphragm pump and particulate filter before being deposited into a 3 × 4.5-ft Tedlar plastic bag. The flow rate of 10 CFH is continuous during the 23-min-long driving cycle and offers plenty of time and surface area for the higher boiling diesel exhaust hydrocarbons to condense and be lost from the sample.

TABLE 8. MERCEDES 220 DIESEL 1972 FEDERAL TEST RESULTS
(All Values in Grams/Mile)

Note: The diesel is not covered by the 1972 Light-Duty Procedure.

		Run No. 1 5/28/71	2 6/1/71	3 6/2/71	4 6/3/71	5 6/4/71	Average
HC, SwRI FIA Heated*							
CVS Bag		0.25	0.26	0.31	0.25	0.36	0.29
CVS Continuous†		0.86	0.82	0.92	0.71	1.06	0.87
HC, Beckman FIA‡							
CVS Bag		0.27	0.27	0.23	0.18	0.18	0.22
CVS Continuous†		0.28	0.38	0.30	0.26	0.23	0.29
CO, NDIR		1.62	1.61	1.60	1.55	1.73	1.62
NO (as NO)	NDIR	0.47	0.59	0.47	0.46	0.39	0.47
	Electrochem**	0.73	1.07	0.29	0.33	0.33	0.55
	Chemilum††						0.42
NO_x (as NO_2)	Saltzman	1.28	1.34	1.46	1.09	1.22	1.27
	Chemilum						1.83
Formaldehyde		0.014	0.018	0.009	0.018	0.018	0.015
Aliphatic Aldehydes (as formaldehyde)		0.022	0.018	0.016	0.025	0.020	0.020
Acrolein		0.012	0.010	0.019	0.019	0.013	0.013

*Heated lines and analyzer at 375°F.
†Entire 23-min run hand-integrated on 1-sec intervals.
‡Model 400 heated analyzer at 100°F.
**Envirometrics Faristor.
††Single run made 6/14/71 with new Thermo Electron Instrument.

To demonstrate this and to attempt to obtain as accurate and reliable information on hydrocarbons as possible, two different hydrocarbon analyzers were utilized. The first was the SwRI heated FIA in which sampling and detection is achieved at 375° F. This instrument normally is used for diesel or gas turbine exhaust where distillate type fuels are employed. The other instrument was the same Beckman 400 FIA used to monitor the hydrocarbons from the CVS runs with the Mercedes 220 gasoline vehicle. The Beckman unit holds the burner and associated detector components at about 100° F and is normally used only on gasoline- or gaseous-fueled engines.

The sample was split at the blower inlet to both instruments, which were operated continuously during the 23-min run, as well as pumped into the holding bag for composite analysis as usual at the end of the run. The continuous trace was time-integrated at 1-sec intervals for the entire 23-min run for both types of FIA's, one incorporating all heated sample handling and the other room temperature sampling. The results shown at the top of Table 8 demonstrate the need for heated lines, sampling systems, and analysis equipment when measuring even diluted diesel exhaust. The only set of HC information considered reliable was the continuous trace taken with the SwRI heated equipment. Bag samples analyzed by either 375° FIA or 100° FIA were nearly the same and substantially lower, approximately one-third, than the continuous high-temperature integrated results. The low-temperature continuous results were likewise about a third of the considered reliable results. In short, it is not an easy task to obtain a precise or absolute indication of hydrocarbons from a diesel-powered vehicle sampled by the CVS method. The

0.87 g/mile HC, which is considered most reliable, is substantially less than that of its sister gasoline-powered Mercedes 220 of 2.68 g/mile (Table 7) as expected.

The average CO, by NDIR, is listed next and was found for the five runs made to be 1.62 g/mile. This is about 5% of the 32.34 g/mile for the Mercedes 220 (Table 7) and was also as expected. Repeatability of the CO measurements is considered excellent.

Measurements of NO, by NDIR, Envirometrics Faristor, and a separate, single run with the new TECO chemiluminescence instruments, are listed next on Table 8 and show surprisingly good agreement. Results of NO_x as NO_2 by Saltzman and the TECO instrument are then listed and are not too far apart considering only a single run was made with the TECO instrument. What is of some concern, at first thought, is the somewhat lower grams of NO and NO_2 per mile with the diesel compared to the gasoline-powered Mercedes tested. The diesel Mercedes exhibited from one-fourth (for NO) to one-half (for NO_x as NO_2) the levels of the gasoline Mercedes. It has been thought, and is felt to be generally true, that the diesel engine produces about as much oxides of nitrogen as the gasoline engine, all other things being equal.

Recall, however, the 13-mode cycle results listed on Table 5 of this report. These were found to be about half that of most diesel truck and bus engines tested by SwRI to date. Of course, some engine designs, such as the Caterpillar turbocharged prechamber 1674 diesel truck engine, have even lower NO_x than the Mercedes and a few engines have NO_x in the neighborhood of the 220 D tested. So, it would follow that the NO_x should also be lower by the

LA-4 driving schedule. Incidentally, the raw concentrations of NO measured during the odor runs pointed toward low NO_x and further confirm these results.

Presented last on Table 8 are the partial oxygenate readings. Though the run-to-run variability was not particularly bad, the magnitude relative to that for the gasoline 220 Mercedes is somewhat puzzling. No really adequate explanation for the formaldehyde, aliphatic aldehydes, and acrolein being about one-fourth that of the gasoline engine can be offered. The consistency of the difference indicates it was real and not due to sampling or analysis difficulties.

In summary of this section, comparable tests of the 220 D and 220 gasoline-powered Mercedes automobiles by the 1972 procedure revealed that the diesel produces about 30% as much HC, 5% as much CO, and about 50% as much NO_x as the gasoline 220. Hydrocarbon measurement of constant volume sampling of diesel exhaust is tricky and should be taken continuously at the inlet to the CVS blower and not be bagged. Heated (e.g., 375° F) sample lines and a heated FIA instrument should be employed to measure as much of the hydrocarbons in the exhaust as possible. Partial oxygenates such as acrolein, aliphatic aldehydes, and formaldehyde were substantially lower from the diesel than from the gasoline engine. Though other differences in say HC, CO, and NO seemed quite justifiable, the disparity in oxygenate results are puzzling and will require further study to explain. The lack of a suitable chemiluminescence instrument, recently specified as the method for NO_x measurement for 1973, was the major drawback of this series of tests, even though a separate single run was made with such an instrument.

VIII. SUMMARY

Two similar Mercedes passenger cars, one powered by a four-cylinder gasoline spark-ignition engine and the other powered by a four-cylinder diesel engine have been subjected to exhaust emissions tests. Odor, smoke, and gaseous tailpipe emissions were measured from the diesel, and hydrocarbons, carbon monoxide, oxides of nitrogen, and several partially oxygenated materials were measured from both cars using the 1972 Federal Test Procedure for light-duty vehicles.

In summary of the diesel odor smoke and cyclic emissions tests, odor under certain driving conditions was as intense as old style injector-equipped city buses powered by two-stroke engines with a more penetrating, yet less kerosene characteristic, odor quality. Hydrocarbons, acrolein, and aldehydes seemed to correlate well with odor ratings, and they too were indicative of an old style diesel bus under intense odor conditions. Federal cycle smoke was on the order of 10% (both "a" and "b" factor), a noticeable level, while relatively low oxides of nitrogen were responsible for the respectable 7 g of HC + NO_2 obtained during the 13-mode California ARB-EMA test procedure.

Comparable tests of the 220 D and 220 gasoline-powered Mercedes automobiles by the 1972 procedure revealed that the diesel produces about 30% as much HC, 5% as much CO, and about 50% as much NO_x as the gasoline 220. Hydrocarbon measurement of constant volume sampling of diesel exhaust is tricky and should be taken continuously at the inlet to the CVS blower and not bagged. Heated (e.g., 375° F) sample lines and heated FIA instrument should be employed to measure as much of the hydrocarbons in the exhaust as possible.

Partial oxygenates such as acrolein, aliphatic aldehydes, and formaldehyde were substantially lower from the diesel than from the gasoline engine. Though other differences in HC, CO, and NO seemed quite justifiable, the disparity in oxygenate results are puzzling and will require further study to explain. The lack of a suitable chemiluminescence instrument, recently specified as the method for NO_x measurement for 1973, was the major drawback of this series of tests even though a separate, single run was made with such an instrument.

In closing, this somewhat limited series of tests represents several firsts to our knowledge. This was the first odor and smoke test of a diesel powered passenger car using the PHS odor rating kit and opacity smokemeter. It was the first test of Mercedes 220 D cyclic emissions using the chassis alternative of the California ARB procedure. Though probably not a first, comparable tests were made of both gasoline- and diesel-powered cars using the new 1972 Federal Test Procedure. Finally, it must be recognized that only one diesel and one gasoline car were studied and problems did occur with diesel hydrocarbon measurement during the 1972 test method. Also, oxides of nitrogen data are not as firm as desired. Accordingly, the results should be used with care, and, of course, extrapolation to all Mercedes diesel and gasoline engines is not justified nor is extrapolation of the data to all diesel and gasoline engines possible.

LIST OF REFERENCES

1. Federal Register, Volume 33, No. 108, June 4, 1968.

2. Federal Register, Volume 35, No. 219, November 10, 1970.

3. "Engine Manufacturers Association Proposed Diesel Emission Approval Procedure for the State of California Air Resources Board," prepared by The Gaseous Emission Subcommittee of the Emission Standards Committee, Draft No. 7.

4. Federal Register, Volume 36, No. 84, April 30, 1971.

5. Bascom, R.C. and Hass, G.C., "A Status Report on the Development of the 1973 California Diesel Emissions Standards," SAE Paper No. 700671, National West Coast Meeting, Los Angeles, California, August 24-27, 1970.

6. Turk, Amos, "Selection and Training of Judges for Sensory Evaluation of the Intensity and Character of Diesel Exhaust Odors," U.S. Department of Health, Education, and Welfare, Public Health Service, 1967.

7. Springer, Karl J. and Stahman, Ralph C., "An Investigation of Diesel-Powered Vehicle Odor and Smoke," National Petroleum Refiners Association, FL-66-46 presented at the Fuels and Lubricants Meeting, Philadelphia, Pennsylvania, September 15-16, 1966.

8. Stahman, Ralph C.; Kittredge, George; and Springer, Karl, "Smoke and Odor Control for Diesel-Powered Trucks and Buses," SAE Paper No. 680443, Mid-Year Meeting, Detroit, Michigan, May 20-24, 1968.

9. Springer, Karl J., "An Investigation of Diesel-Powered Vehicle Odor and Smoke, Part I," Final Report, Contract No. PH 86-66-93, March 1967.

10. Springer, Karl J. and Dietzmann, Harry E., "Diesel Exhaust Hydrocarbon Measurement - A Flame-Ionization Method," SAE Paper No. 700106, Automotive Engineering Congress, Detroit, Michigan, January 12-16, 1970.

11. Springer, Karl J., "An Investigation of Diesel-Powered Vehicle Odor and Smoke, Part II," Final Report, No. AR-644, Contract No. PH 86-67-72, February 1968.

12. Springer, Karl J. and Dietzmann, Harry E., "An Investigation of

Diesel-Powered Vehicle Odor and Smoke, Part IV," Final Report No. AR 802, Contract PH 22-68-23, April 1971.

13. Federal Register, Volume 36, No. 40, February 27, 1971.

APPENDIX A

ODOR AND GASEOUS EMISSIONS

FROM

MERCEDES 220 D AUTOMOBILE

TABLE A1. VEHICLE ODOR EVALUATION SUMMARY

Date: May 10, 1971 Vehicle: Mercedes 220 D

Run No.	Condition	Load	"D" Composite	"B" Burnt	"O" Oily	"A" Aromatic	"P" Pungent
4	2500 rpm	0	5.8	2.0	1.3	1.2	1.1
13	34 mph	0 hp	5.0	1.9	1.2	1.0	1.1
19			6.0	2.0	1.3	1.2	1.3
Avg.			5.6	2.0	1.3	1.1	1.2
1	2500 rpm	1/2	4.3	1.3	1.2	1.0	0.9
8	34 mph	16 hp	3.1	1.0	1.0	0.8	0.1
17			4.3	1.2	1.0	1.0	0.8
Avg.			3.9	1.2	1.1	0.9	0.6
3	2500 rpm	Full	3.9	1.1	1.0	1.0	0.8
12	34 mph	28 hp	3.7	1.0	1.0	1.0	0.3
20			5.3	1.9	1.3	1.2	1.1
Avg.			4.3	1.3	1.1	1.1	0.7
2	4200 rpm	0	5.8	1.9	1.2	1.2	1.4
7	29 mph	0 hp	3.3	1.1	1.0	1.0	0.6
16			5.1	1.7	1.0	1.0	0.9
Avg.			4.7	1.6	1.1	1.1	1.0
9	4200 rpm	1/2	6.2	2.1	1.3	1.1	1.4
15	29 mph	22 hp	6.4	2.0	1.3	1.2	1.6
21			6.1	2.0	1.3	1.1	1.6
Avg.			6.2	2.0	1.3	1.1	1.5
6	4200 rpm	Full	4.9	1.6	1.1	1.0	1.0
10	29 mph	36 mph	4.4	1.3	1.0	1.0	0.9
18			5.8	2.0	1.3	1.3	1.2
Avg.			5.0	1.8	1.1	1.1	1.0
5	Idle		4.1	1.1	1.1	0.9	1.0
11			3.9	1.1	1.0	1.0	0.7
14			4.1	1.1	1.1	1.0	1.0
Avg.			4.0	1.1	1.1	1.0	0.9
22	Idle-Accel-		4.8	1.8	1.0	1.1	1.0
26	eration		4.8	1.6	1.0	1.0	1.0
30			5.1	1.9	1.1	1.0	1.0
31			4.6	1.6	1.0	1.0	1.0
Avg.			4.8	1.7	1.0	1.0	1.0
24	Accelera-		5.0	1.8	1.0	1.1	1.0
27	tion		5.2	1.9	1.1	1.0	1.1
28			5.4	1.9	1.2	0.9	1.2
33			5.4	2.2	1.8	1.0	1.4
Avg.			5.3	2.0	1.3	1.0	1.2
23	Decelera-		7.9	2.3	1.8	1.4	2.2
25	tion		6.2	2.0	1.5	1.2	1.6
29			7.1	2.2	1.7	1.1	2.0
32			6.7	2.1	1.6	1.2	1.7
Avg.			7.0	2.2	1.7	1.2	1.9

TABLE A2. VEHICLE ODOR EVALUATION SUMMARY

Date: May 11, 1971 Vehicle: Mercedes 220 D

Run No.	Condition	Load	"D" Composite	"B" Burnt	"O" Oily	"A" Aromatic	"P" Pungent
4	2500 rpm	0	6.7	2.1	1.9	0.9	1.6
12	34 mph	0 hp	6.1	1.9	1.4	1.2	1.6
17			6.0	2.0	1.6	1.0	1.6
Avg.			6.3	2.0	1.6	1.0	1.6
5	2500 rpm	1/2	4.3	1.3	1.0	1.0	1.0
9	34 mph	15 hp	4.1	1.1	1.1	0.9	1.0
16			3.6	1.0	1.0	0.9	0.4
Avg.			4.0	1.1	1.0	0.9	0.8
1	2500 rpm	Full	2.7	1.0	1.0	0.6	0.1
11	34 mph	28 hp	3.3	1.0	0.9	0.8	0.4
20			3.7	1.1	1.0	0.9	0.7
Avg.			3.2	1.0	1.0	0.8	0.4
2	4200 rpm	0	3.9	1.1	1.0	0.8	0.9
8	29 mph	0 hp	5.7	1.9	1.2	1.0	1.6
10			4.1	1.0	1.0	1.0	0.9
Avg.			4.6	1.3	1.1	0.9	1.1
3	4200 rpm	1/2	5.9	2.0	1.6	1.0	1.3
15	29 mph	18 hp	6.4	2.0	1.6	1.0	1.7
21			6.0	2.2	1.3	0.9	1.8
Avg.			6.1	2.1	1.5	1.0	1.6
6	4200 rpm	Full	5.6	1.9	1.3	0.9	1.1
13	29 mph	36 hp	6.3	1.9	1.6	1.1	1.4
18			5.7	2.0	1.2	1.2	1.4
Avg.			5.9	1.9	1.4	1.1	1.3
7	Idle		4.8	1.6	1.0	1.1	0.9
14			3.1	0.9	0.9	1.0	0.4
19			4.2	1.2	1.1	1.0	1.0
Avg.			4.0	1.2	1.0	1.0	0.8
23	Idle-Accel-		4.7	1.3	1.1	1.0	1.0
25	eration		4.3	1.2	1.1	1.1	1.0
30			4.1	1.2	1.0	0.9	0.9
31			4.0	1.1	1.0	0.9	1.0
Avg.			4.3	1.2	1.1	1.0	1.0
22	Accelera-		5.0	1.6	1.1	0.9	1.1
27	tion		6.1	1.9	1.2	1.0	2.0
29			5.2	1.9	1.2	1.0	1.1
32			4.8	1.7	1.0	1.0	1.1
Avg.			5.3	1.8	1.1	1.0	1.3
24	Decelera-		7.3	2.2	1.8	1.2	2.1
26	tion		5.7	1.7	1.2	1.2	1.4
28			5.6	1.9	1.3	1.0	1.3
33			7.0	2.2	1.6	1.2	1.9
Avg.			6.4	2.0	1.5	1.2	1.7

TABLE A3. VEHICLE ODOR EVALUATION SUMMARY

Date: May 12, 1971 Vehicle: Mercedes 220 D

Run No.	Condition	Load	"D" Composite	"B" Burnt	"O" Oily	"A" Aromatic	"P" Pungent
9	2500 rpm	0	6.7	1.9	1.4	1.1	1.9
12	34 mph	0 hp	5.8	2.0	1.3	1.0	1.4
16			5.7	1.9	1.1	1.1	1.4
Avg.			6.1	1.9	1.3	1.1	1.6
2	2500 rpm	1/2	2.7	1.0	0.9	0.4	0.4
6	34 mph	14 hp	3.2	1.0	1.0	0.8	0.6
10			4.4	1.4	1.0	0.8	1.0
Avg.			3.4	1.1	1.0	0.7	0.7
3	2500 rpm	Full	3.3	1.0	1.0	0.7	0.8
17	34 mph	30 hp	6.1	2.1	1.2	0.8	1.8
20			3.9	1.0	0.9	1.0	1.0
Avg.			4.4	1.4	1.0	0.8	1.2
1	4200 rpm	0	3.7	1.0	1.0	0.9	0.7
7	29 mph	0 hp	4.1	1.0	1.0	0.9	1.0
21			3.9	1.3	1.0	0.9	0.9
Avg.			3.9	1.1	1.0	0.9	0.9
4	4200 rpm	1/2	5.9	2.0	1.1	1.1	1.7
13	29 mph	22 hp	6.3	2.2	1.4	1.1	1.7
19			6.1	2.3	1.1	1.2	1.6
Avg.			6.1	2.2	1.2	1.1	1.7
8	4200 rpm	Full	5.8	1.8	1.3	1.1	1.6
11	29 mph	39 hp	6.1	2.1	1.3	1.0	1.7
14			5.2	1.9	1.3	0.9	1.2
Avg.			5.7	1.9	1.3	1.0	1.5
5	Idle		3.4	1.0	1.0	0.8	0.8
15			3.8	1.1	1.0	0.9	0.8
18			4.2	1.1	1.0	1.1	0.9
Avg.			3.8	1.1	1.0	0.9	0.8
24	Idle-Accel-		3.8	1.2	1.0	1.0	0.4
27	eration		4.1	1.1	1.0	1.0	0.7
28			4.4	1.3	1.0	1.0	1.1
32			4.9	1.7	1.0	1.1	1.1
Avg.			4.3	1.3	1.0	1.0	0.8
23	Accelera-		5.8	2.0	1.3	1.2	1.1
25	tion		4.8	1.4	1.0	1.0	1.2
29			4.3	1.2	1.0	1.0	1.0
33			5.6	1.9	1.1	1.2	1.2
Avg.			5.1	1.6	1.1	1.1	1.1
22	Decelera-		7.0	2.1	1.8	1.1	2.0
26	tion		6.8	2.0	1.8	1.1	2.0
30			7.0	2.2	1.7	1.1	2.0
31			6.8	2.1	1.7	1.1	1.6
Avg.			6.9	2.1	1.8	1.1	1.9

TABLE A4. GASEOUS EMISSIONS MEASURED DURING ODOR EVALUATION

Date: May 10, 1971 Vehicle: Mercedes 220 D

Run No.	Condition	Load	HC, ppm	CO, ppm	NO, ppm	Acrolein, ppm	Formaldehyde, ppm	Aliphatic Aldehydes, ppm
4	2500 rpm	0	988	709	66	7.9	15.9	22.0
13	34 mph	0 hp	1025	722	66	7.9	17.0	30.3
19			1000	750	86	6.8	19.4	31.8
Avg			1004	727	73	7.5	17.4	28.0
1	2500 rpm	1/2	50	152	348	-	17.5	25.7
8	34 mph	16 hp	63	190	348	0.5	16.5	23.6
17			63	203	348	0.7	23.1	27.5
Avg			59	182	348	0.6	19.0	25.6
3	2500 rpm	Full	50	242	452	1.0	6.9	9.2
12	34 mph	28 hp	50	268	475	0.9	8.8	11.6
20			75	333	475	1.4	23.5	15.5
Avg			58	281	467	1.1	13.1	12.1
2	4200 rpm	0	75	320	207	1.8	7.5	8.1
7	29 mph	0 hp	63	333	228	1.4	9.3	13.2
16			63	333	228	2.0	11.4	11.0
Avg			67	329	221	1.7	9.4	10.8
9	4200 rpm	1/2	450	1131	512	3.2	21.1	31.7
15	29 mph	22 hp	525	1307	536	4.1	28.8	36.0
21			213	791	561	3.3	20.4	35.2
Avg			396	1076	536	3.5	23.4	34.3
6	4200 rpm	Full	75	1426	549	0.9	21.3	24.4
10	29 mph	36 mph	63	1160	549	1.2	22.7	32.0
18			38	1486	561	1.2	24.3	31.1
Avg			59	1357	553	1.1	22.8	29.2
5	Idle		163	165	115	2.1	12.5	20.2
11			163	245	115	2.2	12.5	20.4
14			138	203	125	2.2	12.6	22.5
Avg			155	204	118	2.2	12.5	21.0

TABLE A5. GASEOUS EMISSIONS MEASURED DURING ODOR EVALUATION

Date: May 11, 1971 Vehicle: Mercedes 220 D

Run No.	Condition	Load	HC, ppm	CO, ppm	NO, ppm	Acrolein, ppm	Formaldehyde, ppm	Aliphatic Aldehydes, ppm
4	2500 rpm	0	1225	764	66	11.0	15.1	29.9
12	34 mph	0 hp	950	668	66	10.4	14.5	25.0
17			1013	654	76	10.4	18.9	36.0
Avg			1063	695	69	10.6	16.2	30.3
5	2500 rpm	1/2	88	242	337	2.7	18.2	24.9
9	34 mph	15 hp	63	281	292	2.5	15.7	21.7
16			75	203	359	3.2	19.5	26.8
Avg			75	242	329	2.8	17.8	24.5
1	2500 rpm	Full	50	203	475	0.8	5.4	9.8
11	34 mph	28 hp	88	190	500	1.0	6.5	9.6
20			63	139	536	0.8	7.6	10.8
Avg			67	177	504	0.9	6.5	10.1
2	4200 rpm	0	75	346	197	1.0	6.1	10.8
8	29 mph	0hp	88	373	207	1.1	7.2	10.4
10			125	359	207	1.0	10.8	15.2
Avg			96	359	204	1.0	8.0	12.1
3	4200 rpm	1/2	850	1336	487	8.8	13.7	34.4
15	29 mph	18 hp	1075	988	500	9.2	15.6	36.4
21			875	1277	524	9.1	16.9	37.7
Avg			933	1200	504	9.0	15.4	36.2
6	4200 rpm	Full	63	819	586	1.2	28.1	28.8
13	29 mph	36 hp	75	709	612	1.6	29.0	26.5
18			75	709	612	1.6	31.3	28.3
Avg			71	746	603	1.5	29.5	27.9
7	Idle		75	190	115	1.0	11.3	16.7
14			75	139	125	0.9	10.1	15.2
19			88	139	125	0.8	13.7	20.6
Avg			79	156	122	0.9	11.7	17.5

TABLE A6. GASEOUS EMISSIONS MEASURED DURING ODOR EVALUATION

Date: May 12, 1971 Vehicle: Mercedes 220 D

Run No.	Condition	Load	HC, ppm	CO, ppm	NO, ppm	Acrolein, ppm	Formaldehyde, ppm	Aliphatic Aldehydes, ppm
9	2500 rpm	0	1025	778	96	4.5	12.4	26.0
12	34 mph	0 hp	768	654	96	5.2	11.8	24.6
16			825	722	86	5.4	13.7	28.3
Avg.			873	718	93	5.0	12.6	26.3
2	2500 rpm	1/2	63	255	337	0.5	8.9	11.8
6	34 mph	14 hp	75	307	348	0.6	7.7	12.1
10			100	242	337	1.0	9.5	15.4
Avg.			79	268	341	0.7	8.7	13.1
3	2500 rpm	Full	75	190	549	1.0	16.6	11.9
17	34 mph	30 hp	75	139	536	1.4	24.1	24.6
20			50	178	549	1.0	23.9	24.2
Avg.			67	169	545	1.1	21.5	20.2
1	4200 rpm	0	125	373	249	0.7	5.5	13.5
7	29 mph	0 hp	125	373	249	0.9	5.7	14.2
21			63	320	239	0.8	8.0	17.0
Avg.			104	355	246	0.8	6.4	14.9
4	4200 rpm	1/2	975	1131	561	5.9	17.5	30.4
13	29 mph	22 hp	725	1277	536	6.6	22.5	36.7
19			963	1160	536	6.4	23.7	37.6
Avg.			888	1189	544	6.3	21.2	34.9
8	4200 rpm	Full	50	875	651	0.5	12.2	15.2
11	29 mph	39 hp	63	847	625	4.7	11.9	17.7
14			38	681	638	0.5	13.9	21.4
Avg.			50	801	638	1.9	12.7	18.1
5	Idle		63	152	135	1.5	11.2	20.3
15			63	139	135	1.9	13.6	20.0
18			113	139	125	1.9	10.9	15.4
Avg.			80	143	132	1.8	11.9	18.6

APPENDIX B

SMOKE AND EMA CYCLIC EMISSIONS DATA

FROM

MERCEDES 220 D AUTOMOBILE

TABLE B1. FEDERAL CYCLE SMOKE DATA

Vehicle No. Mer. Arg. Benz Date 5-17-71 Evaluated By Cayer W.

Model Engine 220-D Run No.

Accelerations

First Sequence Interval No.	Smoke %	Second Sequence Interval No.	Smoke %	Third Sequence Interval No.	Smoke %
1	14.5	1	9.8	1	13.5
2	26.5	2	13.5	2	15.5
3	11.0	3	16.6	3	10.5
4	11.8	4	10.8	4	12.0
5	11.6	5	12.1	5	10.6
6	11.2	6	10.1	6	13.2
7	7.8	7	9.8	7	9.0
8	9.6	8	9.7	8	8.9
9	9.1	9	8.5	9	8.4
10	8.2	10	9.3	10	7.3
11	7.5	11	8.7	11	7.0
12	7.2	12	8.0	12	6.9
13	7.2	13	8.9	13	7.0
14	9.0	14	8.3	14	7.3
15	8.7	15	8.1	15	7.2
Total Smoke %	159.7		152.2		144.6

Factor (a) = $\frac{156.5}{45}$ = 10.1 %

Lugging

First Sequence Interval No.	Smoke %	Second Sequence Interval No.	Smoke %	Third Sequence Interval No.	Smoke %
1	12.0	1	8.3	1	7.8
2	8.2	2	8.4	2	7.8
3	8.5	3	8.5	3	7.8
4	8.9	4	8.3	4	7.8
5	9.4	5	8.6	5	7.8
Total Smoke %	46.9		42.1		39.0

Factor (b) = $\frac{128.0}{15}$ = 8.5 %

Comments:

TABLE B2. FEDERAL CYCLE SMOKE DATA

Vehicle No. Mercedes-Benz Date 5-17-71 Evaluated By Joyce H

Model Engine 220-D Run No. 2

Accelerations

First Sequence		Second Sequence		Third Sequence	
Interval No.	Smoke %	Interval No.	Smoke %	Interval No.	Smoke %
1	13.0	1	13.2	1	14.2
2	16.4	2	16.9	2	15.8
3	11.4	3	15.0	3	11.5
4	11.2	4	11.5	4	12.1
5	11.9	5	12.2	5	11.5
6	11.1	6	11.2	6	10.6
7	10.7	7	10.3	7	10.0
8	19.5	8	9.6	8	9.8
9	11.3	9	8.9	9	9.0
10	9.2	10	9.9	10	10.2
11	9.9	11	9.5	11	10.3
12	9.8	12	8.9	12	9.3
13	9.1	13	9.0	13	8.8
14	10.3	14	8.8	14	8.5
15	10.2	15	8.3	15	8.6
Total Smoke %	174.5		163.3		160.8

Factor (a) = $\frac{498.6}{45}$ = 11.1 %

Lugging

First Sequence		Second Sequence		Third Sequence	
Interval No.	Smoke %	Interval No.	Smoke %	Interval No.	Smoke %
1	10.1	1	9.5	1	10.1
2	9.2	2	10.0	2	10.6
3	10.2	3	10.3	3	10.9
4	10.0	4	10.0	4	10.8
5	9.1	5	9.4	5	10.3
Total Smoke %	48.6		49.2		52.7

Factor (b) = $\frac{150.5}{15}$ = 10.3 %

Comments:

TABLE B5. FEDERAL CYCLE SMOKE DATA

Vehicle No. Mercedes Benz Date 5-17-71 Evaluated By Joyce

Model Engine 220-D Run No. 3

Accelerations

First Sequence		Second Sequence		Third Sequence	
Interval No.	Smoke %	Interval No.	Smoke %	Interval No.	Smoke %
1	15.2	1	12.5	1	12.0
2	15.6	2	16.2	2	16.0
3	14.0	3	15.5	3	16.3
4	12.5	4	11.9	4	13.0
5	13.3	5	13.0	5	12.9
6	11.5	6	11.2	6	11.5
7	11.1	7	10.9	7	12.0
8	11.4	8	16.8	8	11.9
9	11.6	9	10.2	9	10.4
10	9.9	10	9.5	10	10.0
11	8.4	11	11.5	11	9.5
12	9.0	12	11.5	12	9.3
13	9.0	13	11.0	13	9.1
14	8.5	14	10.8	14	9.3
15	8.6	15	10.3	15	9.6
Total Smoke %	169.6		176.3		172.8

Factor (a) = $\frac{518.7}{45}$ = 11.5 %

Lugging

First Sequence		Second Sequence		Third Sequence	
Interval No.	Smoke %	Interval No.	Smoke %	Interval No.	Smoke %
1	11.0	1	9.5	1	9.9
2	11.0	2	9.9	2	9.9
3	10.3	3	10.0	3	9.9
4	10.1	4	9.8	4	9.9
5	11.1	5	9.2	5	9.8
Total Smoke %	53.5		48.4		49.4

Factor (b) = $\frac{151.3}{15}$ = 10.1 %

Comments:

TABLE B4. FEDERAL CYCLE SMOKE DATA

Vehicle No. Mercedes Benz Date 5-17-71 Evaluated By Joyce Ui

Model Engine 220 D Run No. 2

Accelerations

First Sequence		Second Sequence		Third Sequence	
Interval No.	Smoke %	Interval No.	Smoke %	Interval No.	Smoke %
1	17.0	1	16.8	1	17.0
2	14.0	2	16.1	2	16.8
3	10.9	3	12.6	3	14.5
4	10.9	4	16.1	4	12.8
5	11.5	5	12.3	5	14.0
6	9.3	6	11.0	6	13.0
7	9.0	7	10.1	7	11.9
8	8.3	8	9.1	8	12.2
9	7.5	9	8.5	9	11.0
10	8.0	10	8.0	10	10.2
11	7.1	11	7.1	11	10.0
12	7.1	12	8.2	12	9.9
13	7.7	13	8.3	13	10.1
14	7.1	14	8.2	14	10.6
15	6.6	15	5.1	15	10.0

Total Smoke % 142.2 157.4 154.0

Factor (a) = $\frac{453.6}{45}$ = 10.7 %

Lugging

First Sequence		Second Sequence		Third Sequence	
Interval No.	Smoke %	Interval No.	Smoke %	Interval No.	Smoke %
1	6.3	1	8.3	1	10.3
2	7.0	2	8.4	2	10.6
3	7.5	3	9.1	3	10.9
4	7.0	4	8.5	4	10.8
5	6.4	5	9.0	5	10.8

Total Smoke % 34.2 44.3 53.6

Factor (b) = $\frac{132.1}{15}$ = 8.8 %

Comments: _____

TABLE B5. 13-MODE CYCLE GASEOUS EMISSIONS

Vehicle: Mercedes 220D Date: May 10, 1971 Mileage: 16,281

RUN 1

MODE	C_nH_m, ppm	CO, ppm	NO, ppm	ENGINE SPEED, rpm	OBSERVED POWER, bhp	AIR FLOW, lb/min.	FUEL FLOW, lb/min.	EXHAUST FLOW, lb/min.	g/hr C_nH_m (weighted)	g/hr CO (weighted)	g/hr NO (weighted)	OBSERVED bhp (weighted)
1	250	190	96	680	———	1.54	.01	1.55	.34	.52	.28	———
2	1175	722	51	2520	———	5.80	.08	5.88	7.30	8.93	.76	———
3	625	627	145	"	10	5.80	.12	5.92	3.91	7.81	1.94	.80
4	138	242	337	"	22	5.80	.19	5.99	.87	3.05	4.55	1.76
5	112	190	464	"	32	5.80	.25	6.05	.72	2.42	6.33	2.56
6	88	359	487	"	40	5.80	.30	6.10	.57	4.61	6.76	3.20
7	125	165	115	680	———	1.54	.01	1.55	.17	.45	.34	———
8	50	1016	561	4200	58	8.88	.53	9.41	.50	20.12	11.91	4.64
9	75	600	612	"	41	8.88	.42	9.30	.74	11.74	12.84	3.28
10	550	1248	549	"	28	8.88	.34	9.22	5.35	24.21	11.42	2.24
11	338	373	382	"	15	8.88	.28	9.16	3.27	7.19	7.89	1.20
12	88	333	239	"	———	8.88	.20	9.08	.84	6.36	4.90	———
13	100	165	115	680	———	1.54	.01	1.55	.14	.45	.34	———
								TOTALS	24.72	97.86	70.20	19.68

RUN 2

MODE	C_nH_m, ppm	CO, ppm	NO, ppm	ENGINE SPEED, rpm	OBSERVED POWER, bhp	AIR FLOW, lb/min	FUEL FLOW, lb/min	EXHAUST FLOW, lb/min	g/hr C_nH_m (weighted)	g/hr CO (weighted)	g/hr NO (weighted)	OBSERVED bhp (weighted)
1	175	190	96	680	———	1.54	.01	1.55	.24	.52	.28	———
2	1038	681	66	2520	———	5.80	.09	5.89	6.46	8.44	.88	———
3	638	654	156	"	10	5.80	.12	5.92	3.99	8.15	2.08	.80
4	138	242	348	"	22	5.80	.19	5.99	.87	3.05	4.70	1.76
5	125	190	487	"	33	5.80	.26	6.06	.80	2.42	6.66	2.64
6	88	268	512	"	40	5.80	.30	6.10	.57	3.44	7.05	3.20
7	112	152	125	680	———	1.54	.01	1.55	.15	.42	.37	———
8	50	875	586	4200	57	8.88	.52	9.40	.50	17.31	12.43	4.56
9	75	532	612	"	41	8.88	.42	9.30	.74	10.41	12.84	3.28
10	625	1219	561	"	28	8.88	.34	9.22	6.09	23.65	11.67	2.24
11	325	359	370	"	14	8.88	.27	9.15	3.14	6.91	7.64	1.12
12	75	307	218	"	———	8.88	.19	9.07	.72	5.86	4.46	———
13	125	178	115	680	———	1.54	.01	1.55	.17	.49	.34	———
								TOTALS	24.44	91.07	71.40	19.60

g/hr C_nH_m = 0.0132 (ppm C_1H_n) (EXH. FLOW, lb/min) (Weight Factor)

g/hr CO = 0.0263 (ppm CO) (EXH. FLOW, lb/min) (Weight Factor)

g/hr NO = 0.0782 (ppm NO) (EXH. FLOW, lb/min) (Weight Factor)

	RUN 1	RUN 2	RUN 3
BSHC, g/bhp-hr	1.26	1.25	1.30
BSCO, g/bhp-hr	4.97	4.65	4.94
BSNO, g/bhp-hr	3.57	3.64	3.50
$BSNO_2$, g/bhp-hr	5.47	5.58	5.37
$BSNO_x$ + BSHC, g/bhp-hr	6.73	6.83	6.67

TABLE B5. 13-MODE CYCLE GASEOUS EMISSIONS (Cont'd)

Vehicle: Mercedes 220D **Date: May 10, 1971** **Mileage: 16,281**

RUN 3

MODE	C_nH_m, ppm	CO, ppm	NO, ppm	ENGINE SPEED, rpm	OBSERVED POWER, bhp	AIR FLOW, lb/min.	FUEL FLOW, lb/min.	EXHAUST FLOW, lb/min.	g/hr C_nH_m (weighted)	g/hr CO (weighted)	g/hr NO (weighted)	OBSERVED bhp (weighted)
1	238	203	86	680	—o—	1.54	.01	1.55	.33	.55	.25	—o—
2	102.5	600	57	2520	---o---	5.80	.09	5.89	6.38	7.44	.76	—o—
3	625	600	145	"	10	5.80	.12	5.92	3.91	7.47	1.94	.80
4	150	229	337	"	21	5.80	.18	5.98	.95	2.88	4.55	1.68
5	125	152	475	"	31	5.80	.29	6.09	.80	1.95	6.53	2.48
6	75	229	500	"	39	5.80	.30	6.10	.48	2.94	6.88	3.12
7	125	152	125	680	—o—	1.54	.01	1.55	.17	.42	.37	—o—
8	50	1074	561	4200	59	8.88	.50	9.38	.50	21.20	11.87	4.72
9	75	627	586	"	40	8.88	.42	9.30	.75	12.27	12.29	3.20
10	800	1426	524	"	28	8.88	.33	9.21	7.78	27.63	10.89	2.24
11	225	307	337	"	15	8.88	.24	9.12	2.17	5.89	6.93	1.20
12	88	268	218	"	—o—	8.88	.18	9.06	.84	5.11	4.46	—o—
13	125	126	106	680	—o—	1.54	.01	1.55	.17	.34	.31	—o—
								TOTALS	25.23	96.09	68.03	19.44

RUN 4

MODE	C_nH_m, ppm	CO, ppm	NO, ppm	ENGINE SPEED, rpm	OBSERVED POWER, bhp	AIR FLOW, lb/min	FUEL FLOW, lb/min	EXHAUST FLOW, lb/min	g/hr C_nH_m (weighted)	g/hr CO (weighted)	g/hr NO (weighted)	OBSERVED bhp (weighted)
1					———							———
2					———							———
3												
4												
5												
6												
7					———							———
8												
9												
10												
11												
12					———							———
13					———							———
								TOTALS				

	RUN 1	RUN 2
BSHC, g/bhp hr		
BSCO, g/bhp hr		
BSNO, g/bhp hr		

$g/hr\ C_nH_m = 0.0132(ppm\ C_nH_m)(EXH.FLOW, lb/min)(Weight\ Factor)$

$g/hr\ CO = 0.0263(ppm\ CO)(EXH.FLOW, lb/min)(Weight\ Factor)$

$g/hr\ NO = 0.0782(ppm\ NO)(EXH.FLOW, lb/min)(Weight\ Factor)$

TABLE B6. 13-MODE CYCLE GASEOUS EMISSIONS

Vehicle: Mercedes 220D Date: May 11, 1971 Mileage: 16,380

RUN 1

MODE	C_nH_m, ppm	CO, ppm	NO, ppm	ENGINE SPEED, rpm	OBSERVED POWER, bhp	AIR FLOW, lb/min.	FUEL FLOW, lb/min.	EXHAUST FLOW, lb/min.	g/hr C_nH_m (weighted)	g/hr CO (weighted)	g/hr NO (weighted)	OBSERVED bhp (weighted)
1	200	190	96	680	—o—	1.54	.02	1.56	.28	.52	.28	—o—
2	975	654	57	2520	---o---	5.80	.09	5.89	6.06	8.10	.76	—o—
3	600	372	156	"	10	5.80	.13	5.93	3.76	7.14	2.09	.80
4	150	216	370	"	21	5.80	.18	5.98	.95	2.72	4.97	1.68
5	125	165	487	"	32	5.80	.24	6.04	.80	2.10	6.64	2.56
6	88	178	512	"	39	5.80	.29	6.09	.57	2.28	7.03	3.12
7	150	126	106	680	—o—	1.54	.02	1.56	.21	.35	.31	—o—
8	62	532	612	4200	55	8.88	.51	9.39	.61	10.51	12.96	4.40
9	72	465	639	"	41	8.88	.42	9.30	.74	9.10	13.39	3.28
10	100	1307	561	"	28	8.88	.34	9.22	6.82	25.35	11.67	2.24
11	325	323	405	"	12	8.88	.26	9.14	3.14	6.40	8.35	.96
12	88	281	239	"	—o—	8.88	.20	9.08	.84	5.37	4.90	—o—
13	112	126	115	680	—o—	1.54	.02	1.56	.15	.35	.34	—o—
								TOTALS	24.93	80.29	73.71	19.04

RUN 2

MODE	C_nH_m, ppm	CO, ppm	NO, ppm	ENGINE SPEED, rpm	OBSERVED POWER, bhp	AIR FLOW, lb/min	FUEL FLOW, lb/min	EXHAUST FLOW, lb/min	g/hr C_nH_m (weighted)	g/hr CO (weighted)	g/hr NO (weighted)	OBSERVED bhp (weighted)
1	200	216	96	680	—o—	1.54	.02	1.56	.28	.59	.28	—o—
2	975	654	76	2560	—o—	5.80	.09	5.89	5.44	8.10	1.01	—o—
3	450	586	197	"	12	5.80	.13	5.93	2.82	7.31	2.64	.96
4	125	268	393	"	22	5.80	.19	5.99	.79	3.38	5.31	1.76
5	12.5	216	524	"	31	5.80	.24	6.04	.80	2.75	7.14	2.48
6	88	255	561	"	40	5.80	.30	6.10	.57	3.27	7.72	3.20
7	112	178	135	680	—o—	1.54	.02	1.56	.15	.49	.40	—o—
8	62	764	651	4200	54	8.88	.50	9.38	.61	15.08	13.78	4.33
9	88	654	690	"	42	8.88	.42	9.30	.86	12.80	14.48	3.36
10	675	1248	612	"	27	8.88	.34	9.22	6.57	24.21	12.73	2.16
11	250	386	440	"	12	8.88	.26	9.14	2.41	7.43	9.07	.76
12	88	346	282	"	—o—	8.88	.20	9.08	.84	6.61	5.78	—o—
13	112	152	125	680	—o—	1.54	.02	1.56	.15	.42	.37	—o—
								TOTALS	22.29	92.43	80.71	17.20

$g/hr\ C_nH_m = 0.0132(ppm\ C_1H_n)(EXH.FLOW, lb/min)(Weight\ Factor)$

$g/hr\ CO = 0.0263(ppm\ CO)(EXH.FLOW, lb/min)(Weight\ Factor)$

$g/hr\ NO = 0.0782(ppm\ NO)(EXH.FLOW, lb/min)(Weight\ Factor)$

	RUN 1	RUN 2	Run 3
BSHC, g/bhp-hr	1.30	1.16	1.06
BSCO, g/bhp-hr	4.22	4.81	4.29
BSNO, g/bhp-hr	3.87	4.20	4.08
$BSNO_x$, g/bhp-hr	5.93	6.44	6.26
$BSNO_x$ + BSHC, g/bhp-hr	7.23	7.60	7.32

TABLE B6. 13-MODE CYCLE GASEOUS EMISSIONS (Con'd)

Vehicle: Mercedes 220D Date: May 11, 1971 Mileage: 16,380

RUN 3

MODE	C_nH_m, ppm	CO, ppm	NO, ppm	ENGINE SPEED, rpm	OBSERVED POWER, bhp	AIR FLOW, lb/min.	FUEL FLOW, lb/min.	EXHAUST FLOW, lb/min.	g/hr C_nH_m (weighted)	g/hr CO (weighted)	g/hr NO (weighted)	OBSERVED bhp (weighted)
1	200	216	96	680	— o —	1.54	.02	1.56	.27	.59	.28	—o—
2	825	572	76	2520	--- o ---	5.80	.09	5.89	5.13	7.09	1.01	—o---
3	362	586	176	"	10	5.80	.12	5.92	2.26	7.30	2.35	.80
4	125	255	393	"	23	5.80	.18	5.98	.79	3.21	5.30	1.84
5	112	203	512	"	32	5.80	.24	6.04	.71	2.58	6.98	2.56
6	75	190	561	"	40	5.80	.29	6.09	.48	2.43	7.71	3.20
7	150	165	125	680	—o—	1.54	.02	1.56	.28	.45	.37	—o—
8	62	736	637	1200	54	8.88	.51	9.39	.61	14.54	13.49	4.32
9	75	572	677	"	41	8.88	.42	9.30	.74	11.19	14.20	3.28
10	525	1074	612	"	90	8.88	.34	9.22	5.11	20.83	12.73	2.40
11	312	346	416	"	12	8.88	.26	9.14	3.01	6.65	8.58	.96
12	112	307	271	"	—o—	8.88	.20	9.08	1.07	5.87	5.55	—o--
13	75	126	135	680	—o—	1.54	.02	1.56	.10	.35	.40	—o—
								TOTALS	20.56	83.08	78.95	19.36

RUN 2

MODE	C_nH_m, ppm	CO, ppm	NO, ppm	ENGINE SPEED, rpm	OBSERVED POWER, bhp	AIR FLOW, lb/min	FUEL FLOW, lb/min	EXHAUST FLOW, lb/min	g/hr C_nH_m (weighted)	g/hr CO (weighted)	g/hr NO (weighted)	OBSERVED bhp (weighted)
1					———							———
2					———							———
3												
4												
5												
6												
7					———							———
8												
9												
10												
11												
12					———							———
13					———							———
								TOTALS				

RUN 1 RUN 2

$g/hr\ C_nH_m = 0.0132(ppm\ C_1H_4)(EXH.FLOW, lb/min)(Weight\ Factor)$ BSHC, g/bhp hr

$g/hr\ CO = 0.0263(ppm\ CO)(EXH.FLOW, lb/min)(Weight\ Factor)$ BSCO, g/bhp hr

$g/hr\ NO = 0.0782(ppm\ NO)(EXH.FLOW, lb/min)(Weight\ Factor)$ BSNO, g/bhp hr

TABLE B7. AVERAGE GRAMS OF HC, CO, AND NO PER HOUR AND PER LB OF FUEL
MERCEDES 220 D EVALUATION

Mode	Engine Speed, rpm	Engine Load, % of Max	Fuel Rate, lb/min	Hydrocarbon (HC)		Carbon Monoxide (CO)		Nitric Oxide (NO)	
				Average g/hr	Average g/lb fuel	Average g/hr	Average g/lb fuel	Average g/hr	Average g/lb fuel
2	2520	0	0.09	6.13	68.1	8.02	89.1	0.86	9.6
3	2520	25	0.12	3.44	28.7	7.53	62.8	2.17	18.0
4	2520	50	0.19	0.87	4.6	3.05	16.0	4.90	25.8
5	2520	75	0.25	0.77	3.1	2.37	9.5	4.60	18.4
6	2520	100	0.29	0.54	1.9	3.16	10.9	7.18	24.8
8	4200	100	0.51	0.56	1.1	15.79	31.0	12.65	24.8
9	4200	75	0.42	0.76	1.8	10.90	26.0	13.20	31.4
10	4200	50	0.34	6.57	19.3	25.07	73.7	11.68	34.3
11	4200	25	0.26	2.88	11.1	6.70	25.8	8.04	30.9
12	4200	0	0.19	0.82	4.3	5.78	30.4	4.90	25.8

ERRATA

SwRI Technical Report

entitled

EMISSIONS FROM A GASOLINE- AND DIESEL-POWERED MERCEDES 220 PASSENGER CAR

by

Karl J. Springer

Pages 26, 27, and B-10, Figures 5 and 6 and Table B7, respectively, have been corrected and revised and should be substituted in their entirety in the above cited report issued under contract No. CPA 70-44.

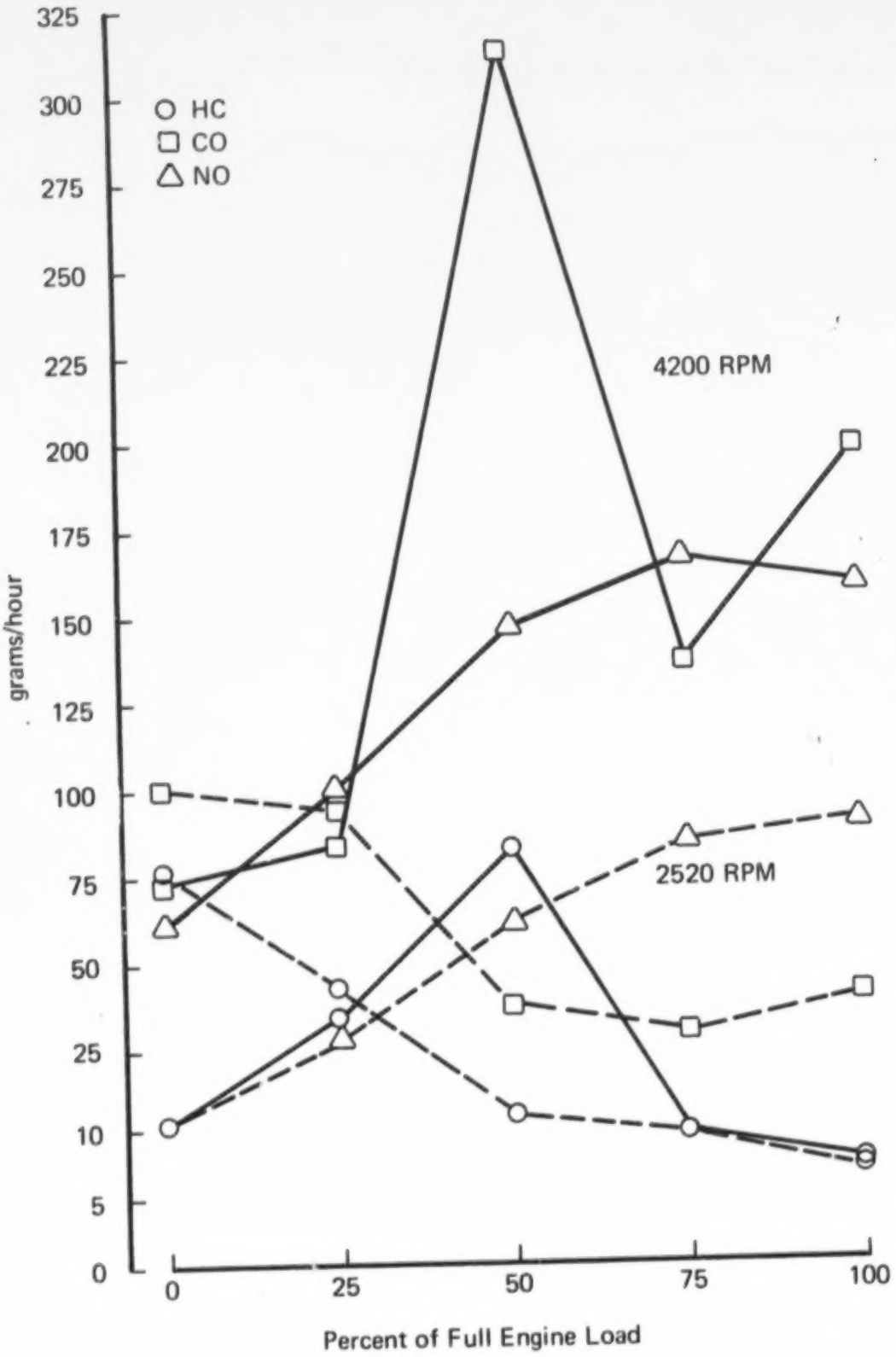


FIGURE 5. AVERAGE GRAMS OF HC, CO, AND NO PER HOUR - MERCEDES 220D

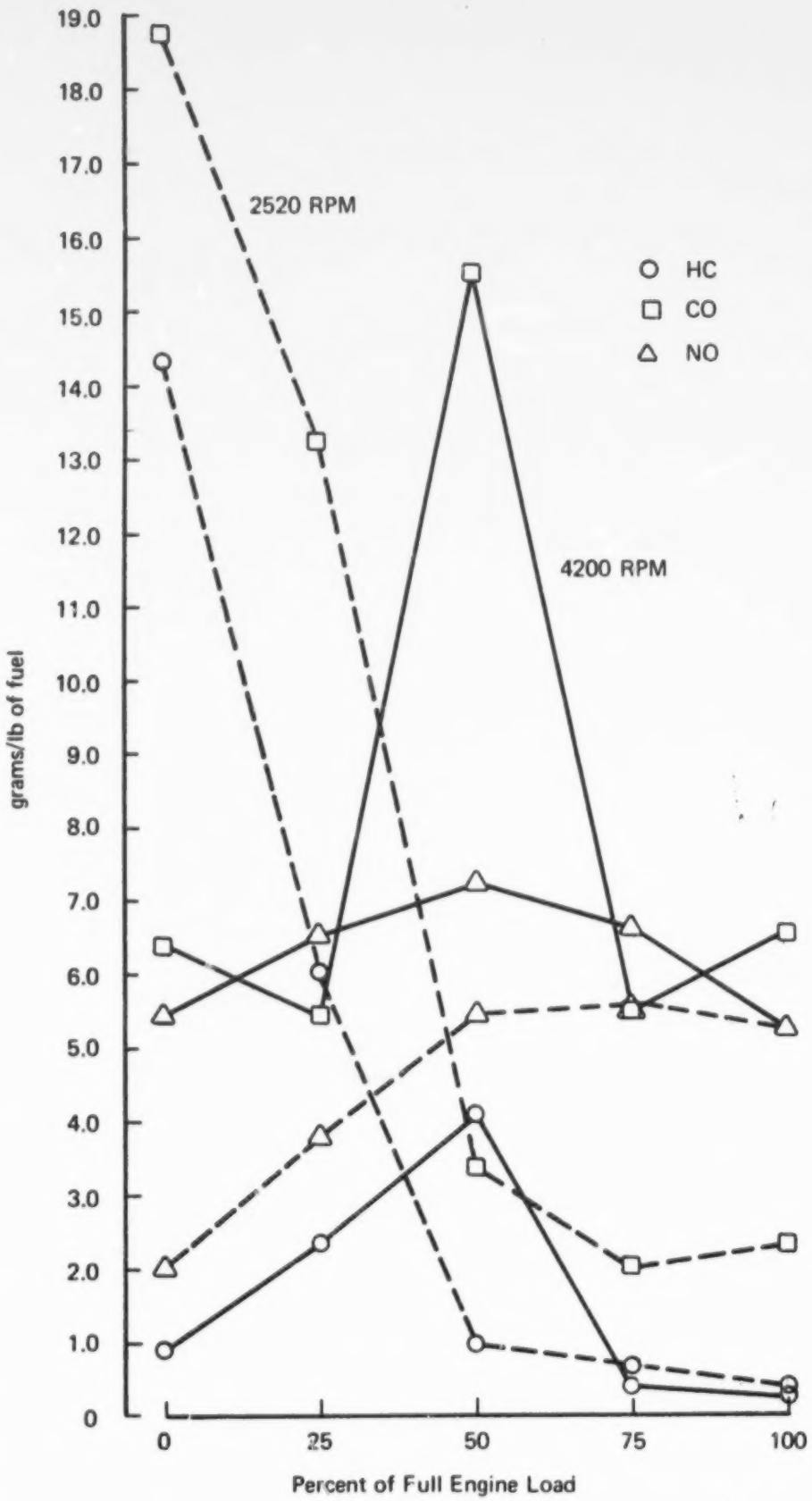


FIGURE 6. AVERAGE GRAMS OF HC, CO, AND NO PER LB. OF FUEL MERCEDES 220D

TABLE B-7. AVERAGE GRAMS OF HC, CO, AND NO PER HOUR AND PER LB OF FUEL, MERCEDES 220D EVALUATION

Mode	Engine Speed, RPM	Engine Load, % of Max	Fuel Rate, lb/hour	Hydrocarbons (HC)		Carbon Monoxide (CO)		Nitric Oxide (NO)	
				Average g/hr	Average g/lb fuel	Average g/hr	Average g/lb fuel	Average g/hr	Average g/lb fuel
2	2520	0	5.4	76.6	14.2	100.2	18.6	10.8	2.0
3	2520	25	7.2	43.0	6.0	94.1	13.1	27.1	3.8
4	2520	50	11.4	10.9	1.0	38.1	3.3	61.2	5.4
5	2520	75	15.0	9.6	0.6	29.6	2.0	83.9	5.6
6	2520	100	17.4	6.8	0.4	39.5	2.3	89.8	5.2
8	4200	100	30.6	7.0	0.2	197.4	6.4	158.1	5.2
9	4200	75	25.2	9.5	0.4	136.2	5.4	165.0	6.5
10	4200	50	20.4	82.1	4.0	313.4	15.4	146.0	7.2
11	4200	25	15.6	36.0	2.3	83.8	5.4	100.5	6.4
12	4200	0	11.4	10.2	0.9	72.2	6.3	61.2	5.4